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REVIEW ARTICLE

# Maternal critical care in resource-limited settings. Narrative review

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**ABSTRACT**
Maternal critical care reflects interdisciplinary care in any hospital area according to the severity of illness of the pregnant woman. The admission rate to intensive care units is below 1% (0.08–0.76%) of deliveries in high-income countries, and ranges from 0.13% to 4.6% in low- and middle-income countries. Mortality in these patients is high and varies from 0% to 4.9% of admissions in high-income countries, and from 2% to 43.6% in low- and middle-income countries. Obstetric haemorrhage, sepsis, preeclampsia, human immunodeficiency virus complications and tropical diseases are the main reasons for intensive care unit admission in low middle-income countries. Bedside assessment tools, such as early warning scores, may help to identify critically ill patients and those at risk of deterioration.
There is a lack of uniformity in definitions, identification and treatment of critically ill pregnant patients, especially in resource-limited settings. Our aims were to (i) propose a more practical definition of maternal critical care, (ii) discuss maternal mortality in the setting of limited accessibility of critical care units, (iii) provide some accessible tools to improve identification of obstetric patients who may become critically ill, and (iv) confront challenges in providing maternal critical care in resource-limited settings. To improve maternal critical care, training programmes should embrace modern technological educational aids and incorporate new tools and technologies that assist prediction of critical illness in the pregnant patient. The goal must be improved outcomes following early interventions, early initiation of resuscitation, and early transfer to an appropriate level of care, whenever possible.


***Keywords***: Maternal critical care; Low- and middle-income countries; Resource-limited settings; Maternal deaths; Obstetric early warning score

## Introduction

Global maternal mortality remains a problem despite recent significant decreases, with the largest proportion of deaths in 2015 occurring in sub-Saharan Africa (201 000 deaths; 66.3%). High-income countries, including North America, Europe, and Australasia, had the lowest maternal mortality rates for 2015. Unfortunately, the current projected maternal mortality rate (MMR) will still be greater than 350 deaths per 100 000 live births in 2030. Only with concerted efforts and implementation of programmes such as the Sustainable Development Goals, will MMR in resource-limited settings (RLS) show significant reductions.[1] Sufficient and appropriate use of critical care facilities is important in addressing global maternal mortality.

In the year 2000, the Department of Health of the United Kingdom recommended that the terms 'Intensive Care' and 'High Dependency' be replaced by 'Critical Care', as it focuses on the level of care that individual patients need, regardless of location.[2] In this concept, also known as 'critical care without walls', each patient's care is subdivided into four levels,[3] depending on the level of organ support and monitoring required, regardless of the diagnosis. The level of care required by the pregnant woman is classified from level 0 (normal

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ward care) to level 3 (support of two or more organ systems).[4] This organ support is usually in the form of respiratory support (basic and advanced), cardiovascular support with inotropic agents, renal replacement therapy, or for other systems such as gastrointestinal, metabolic, haematological or neurological. Level 3 support would include ventilation, or basic respiratory support plus support of at least two other organ systems.

In addition to the level of care provided, a more recent classification of critical care units was proposed within a three-tiered structure: Level 1 describes the "physiologic stabilisation and short-term support of mild organ dysfunction", Level 2 includes "basic support of failing organ function", and Level 3 "complex, comprehensive support and management of organ dysfunction".[5]

Besides the level and structure of critical care units, the code of practice of the physician divides critical care services into: (1) open critical care units, where any physician can prescribe or perform procedures, and management or consultation by a qualified intensive care physician is not mandatory; and (2) closed critical care units, where only the attending critical care physician or staff can prescribe and manage patients. The hybrid model (a combination of open and closed) allows all physicians to prescribe, but requires an on-site critical care physician to provide consultation, conduct rounds, or manage decisions related to patient care.[6]

We will use the term "maternal critical care" (MCC)[7] as a hybrid organisational model, since it reflects interdisciplinary care in any hospital area according to the severity of illness of the pregnant woman. This is in contrast to "obstetric critical care" that represents care by specialists in a dedicated area. Setting a low threshold for early admission of obstetric patients to an MCC model, could contribute to decreasing maternal mortality.[8]

There is a lack of uniformity in definitions, identification and treatment of critically ill pregnant patients throughout the world, especially in RLS.[9] Our aims were to (i) propose a practical definition of maternal critical care, (ii) describe challenges in the admission to, and provision of, MCC, (iii) outline accessible bedside assessment tools to improve identification of critically ill or at-risk obstetric patients, and (iv) discuss innovations addressing the challenges for provision of maternal critical care in RLS.

## Literature search

We conducted a literature search, with no language or date restrictions, in November 2017. The search was performed in the PubMed, SciELO and LILACS databases, using the terms "obstetric" OR "obstetrics" OR "maternal" AND "critical care" OR "intensive care" OR "high dependency" AND "developing world" OR "developing country" OR "developing countries" OR "LMIC" OR "low- and middle-income countries". We also included statements and documents from scientific societies, inter-governmental organisations, and departments of health, related to care of critically ill pregnant women.

## Resource-limited settings and low- and middle-income countries

Since 2016 the World Bank has no longer categorised countries into the groups "developed" and "developing". Rather, countries are classified into four groups based on gross national income (GNI) per capita set each year on July 1st (Table 1).[10] Almost every low-income country (LIC) and many of the lower and upper middle-income countries (LMIC) meet the criteria of RLS.[11] Resource-limited settings countries are characterised by a lack of funds to cover health care costs, either on an individual or societal basis, which leads to the challenges described in Table 2.

In RLS, many health care workers have little or no access to basic, practical information. Indeed, many have come to rely on observation, on advice from colleagues, and on building experience empirically through their own treatment successes and failures. The disparity between theoretical and practical availability of information is due to several factors, including limited Internet access and a failure to apply international development policies and engage with educational

**Table 1 2018 fiscal year World Bank classification of countries according to gross national income per capita in US dollars**

| Income group | GNI per capita US dollars |
|---|---|
| Low-income countries | ≤USD 1005 |
| Lower middle-income countries | USD 1006–3955 |
| Upper middle-income countries | USD 3956–12 235 |
| High-income countries | ≥USD 12 236 |

USD = US dollars; GNI: gross national income.

**Table 2 Characteristics of resource-limited settings**

| |
|---|
| Limited access to medication, equipment, supplies, and devices |
| Poorly developed infrastructure (e.g. electrical power, water supply) |
| Equipment is costly compared to personnel |
| Limited access to maintenance and equipment components |
| Fewer and less well-trained personnel |
| Proper disposal facilities (e.g. incineration), disinfection and sterilisation not always available |
| Transportation of patients to a higher level of care far from the primary healthcare facility |
| Patients rely on government funding for health care |

initiatives. These have tended to focus on approaches for higher-level health professionals, while ignoring other approaches that remain essential for the vast majority of primary healthcare workers.[12]

Healthcare systems within low- and middle-income countries show heterogeneity in access to healthcare, availability of resources, critical care facilities, and healthcare providers. This occurs in different healthcare structures, but is often apparent in countries having a two-tiered system consisting of both public hospitals (state funded) and private hospitals (medical insurance private-based hospitals). For example, in South Africa the private healthcare system serves less than 20% of the population. However, these hospitals have 75% of the critical care/high care beds for the country.[13] These discrepancies in critical care services are also reflected in access to blood products (only about one third of United Nations countries met the World Health Organization's (WHO) recommendations for a national program able to support blood transfusions), and access to specialists in anaesthesia, obstetrics, and critical care.[14] Several countries are also a blend of cities and rural areas, resulting in differences in healthcare provision within the same resource-limited country. Marshall et al. recently reported several of these issues and highlighted the lack of common diagnostic blood tests, microbiological services, radiological investigations, reliable oxygen supplies, and even water and electricity.[5]

## Admission to critical care, and maternal mortality, in lower and low- and middle-income countries

Maternal survival has improved since the adoption of the United Nations Millennium Development Goals, and the global maternal mortality rate has decreased by 44% from 1990 to 2015.[15] In 2015, most of these deaths were in LMICs, where the maternal mortality ratio is 14 times higher than in many high-income countries (HICs). Most of the deaths were deemed preventable and were caused by haemorrhage, sepsis (including human immunodeficiency virus (HIV) and tropical diseases), preeclampsia, complications of delivery, unsafe abortion, and violence.[16]

In more recent years, indirect maternal deaths (for example, underlying embolic and cardiac diseases, associated conditions like multiple gestation, assisted reproductive technologies and obesity) outnumber direct deaths in many HICs. This contrasts with LMICs where the proportion of maternal deaths due to indirect causes increased, but maternal deaths due to direct causes remain high.[17,18]

The percentage of the obstetric population requiring admission to a critical care unit differs between countries and is influenced by socioeconomic status, criteria for critical care admission, and availability of beds.[19] The admission rate to critical care units is below 1% (0.08–0.76%) of deliveries in HICs,[20–23] and ranges from 0.13% to 4.6% in LMICs.[24–30] Mortality in these patients is high and varies from 0% to 4.9% of critical care unit admissions in HICs[20–23] and from 2% to 43.6% in LMICs.[24–30] Obstetric haemorrhage, sepsis, preeclampsia, HIV complications and tropical diseases are the main reasons for critical care admission in LMICs.[24–30] Admission criteria and severity of illness scores in critically ill obstetric patients are discussed elsewhere.[31] It is important to bear in mind that each LMIC must develop guidelines for the admission of pregnant women to critical care units according to their infrastructure and needs.[31–34] Although generalisable critical care admission criteria would be helpful, these are particularly difficult to define. Nates et al. suggested that criteria be determined by the conditions of the individual hospital and country. [35]

## Identifying obstetric patients at risk of becoming critically ill

Identification of critically ill patients has gained increasing attention in critical care literature, particularly with the recent updated publication of the new Surviving Sepsis Guidelines. Of interest is the apparent need for the creation of a simple bedside assessment tool to identify patients at risk, and those who are already critically ill. The Sequential Organ Failure Assessment (SOFA) has been adapted to a shorter format, the Quick SOFA, in an effort to improve the rapidity of identification of septic patients.[36] The lack of available resources, specialised tests, and laboratory services in low-income areas highlights the need for a robust and sensitive maternal early warning score.

### Maternal early warning systems

An early warning system consists of a simple-to-use algorithm based on physiological parameters such as systolic blood pressure, respiratory rate, heart rate, temperature and level of consciousness. This simple scoring tool can easily be utilised during the routine bedside observations and is considered helpful in recognising patients exhibiting signs of acute deterioration, identifying patients who may become critically ill, and improving outcomes by early intervention. Literature is divided regarding the ability of early warning scores to affect mortality outcomes, although even decreasing the number of critical care admissions may be considered an important outcome in RLS. It should be remembered that early warning scores alone probably cannot achieve the desired results, but rather need to be combined with appropriate hospital outreach teams, training, protocols, and even availability of medical advice.[37]

Carle et al. designed and validated the clinically modified Obstetric Early Warning Score (OEWS), based on

a retrospective analysis of 4440 obstetric admissions to critical care units in the United Kingdom.[38] The OEWS is a bedside assessment tool designed to identify women at a higher risk of severe complications, by recording some maternal vital signs, level of consciousness, and pain score every 12 hours. Importantly, it does not require laboratory testing and incorporates a colour scheme as well as a numerical measure of illness severity (Table 3).[38,39] This score also has very good predictive ability for survival after critical care unit admission. Recently, the clinical OEWS has been retrospectively validated in a middle-income country in South America, showing that this score is able to predict survival in conditions directly related to pregnancy.[39] For RLS, a single markedly abnormal observation (red trigger - 3 points), or a combination of two simultaneous mildly abnormal observations (two yellow triggers), or a numerical scale sum of ≥4 points, prompted urgent health worker assessment and early treatment.[40] Importantly, the effect of implementation of OEWS on maternal mortality requires further investigation in low-income settings.

### Disease-related obstetric scoring systems

The shock index (SI) is defined as the ratio between heart rate and systolic blood pressure. It has been proposed as a useful and reliable tool to detect and/or predict hypovolaemia and early haemodynamic compromise in obstetric populations, even when the individual vital signs are within normal values.[41,42] A recent study including 958 patients with hypovolaemic shock secondary to obstetric haemorrhage in RLS, suggested that the SI was a strong predictor of all adverse outcomes. The authors recommended that a SI threshold of 0.9 indicated need for referral, 1.4 indicated an urgent need for transportation to a higher level of care (including surgery and interventional radiology), and a value of 1.7 was associated with a high likelihood of adverse outcomes (admission to a critical care unit, massive transfusion, multiple organ failure and death).[43]

The miniPIERS (Preeclampsia Integrated Estimate of RiSk) risk prediction model, provided a simple tool to identify pregnant women in LMICs at increased risk of death or major complications of preeclampsia. This model included: parity (nulliparity versus multiparity); gestational age on admission; headache/visual disturbances; chest pain/dyspnoea; vaginal bleeding with abdominal pain; systolic blood pressure; and dipstick proteinuria. It can help identify women in LMICs who would benefit most from interventions such as magnesium sulphate, antihypertensives, or transportation to a higher level of care, and was previously shown to have an area-under-the-receiver-operating characteristic curve (AUC ROC) of 0.77 (95% CI: 0.74 to 0.80).[44] Recently the fullPIERS model was used in RLS hospitals to identify women with preeclampsia at high risk of adverse maternal outcomes and in need of immediate interventions. However, this model requires laboratory tests (platelet count, serum creatinine and aspartate transaminase levels), which may limit use in RLS.[45]

## The obstetrically modified quick SOFA score (omqSOFA)

Several modifications are suggested when the Quick SOFA (qSOFA) criteria are applied in pregnancy,

**Table 3 Obstetric early warning score (OEWS)**

| Clinical Parameter | 3 | 2 | 1 | Normal | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|
| **Systolic blood pressure (mm Hg)** | <80 | 80–89 | | 90–139 | 140–149 | 150–159 | ≥160 |
| **Diastolic blood pressure (mm Hg)** | | | | <90 | 90–99 | 100–109 | ≥110 |
| **Respiratory rate (breaths per min)** | <10 | | | 10–17 | 18–29 | | ≥30 |
| **Heart rate (per min)** | <60 | | | 60–110 | | 111–149 | ≥150 |
| **%$O_2$ required to maintain $SpO_2$ 96%** | | | | Room air | 24–39 % | | ≥40 % |
| **Temperature (°C)** | <34.0 | | 34.0–35.0 | 35.1–37.9 | 38.0–38.9 | | ≥39 |
| **Level of consciousness** | | | | Alert* | | | Not alert** |

*Alert: equivalent to Glasgow Coma Score (GCS) 15 and A on Alert/Voice/Pain/Unresponsive (AVPU) scale; **Not alert: GCS 3–14 or V, P, U on AVPU scale.

**Table 4 Obstetrically modified qSOFA score (omqSOFA)**

| Clinical parameter | Score |
|---|---|
| Systolic blood pressure ≤90 mmHg (≤100 mmHg in non-pregnant patient) | 1 |
| Respiratory rate ≥25/min (≥ 22/min in non-pregnant patient) | 1 |
| Altered mentation (any state other than Alert) (Glasgow coma scale <15 in non-pregnant patient) | 1 |

Infection + omqSOFA ≥2 = maternal sepsis.

largely due to associated physiological changes; these modifications, referred to as the obstetrically modified quick SOFA score (omqSOFA), are shown in Table 4.[46]

This score requires only clinical data and can thus be performed quickly without waiting for biochemical or laboratory results, allowing early initiation of resuscitation in patients with suspected sepsis. Healthcare workers should consider a diagnosis of maternal sepsis if a woman has symptoms or signs of, or risk factors for infection, plus the presence of two or more of the omqSOFA clinical parameters.

The omqSOFA, qSOFA and SOFA scores have not undergone appropriate prospective validation in pregnant and postpartum populations. Also, weaknesses have been found in recent publications, in both sensitivity and specificity of qSOFA. Together with the non-validation of this tool, this probably makes it inappropriate to introduce this score into clinical obstetric practice at this stage. There are other simple scoring systems for sepsis in obstetrics, such as the Sepsis in Obstetrics Score (S.O.S). Recently this score was used to identify the risk of critical care unit admission for sepsis, with a threshold score ≥6 having a sensitivity of 64%, specificity of 88%, positive predictive value of 15%, and negative predictive value of 98.6%.[47] However, this score requires laboratory tests (white blood cell count and lactic acid level), which again may limit its use in RLS.[47] The WHO Global Maternal and Neonatal Sepsis Initiative Working Group is currently investigating standardisation of the definition for maternal sepsis and aiming to bring it in line with current definitions of sepsis in the adult population. The results are expected in 2018.[48]

## Challenges to the provision of maternal critical care in resource-limited settings

Maternal critical care in RLS faces challenges similar to those found in general healthcare: lack of drugs, equipment, supporting infrastructure and trained personnel, inadequate transportation, long lead times to hospital admission, evaluation, treatment and transfer to surgical facilities and the critical care unit; as well as late and severe presentations of disease secondary to poor access to appropriate care.[49] In addition, over and above the delays before making the decision to refer, and in reaching the referral site, factors associated with a "third delay", those incurred after arrival at the hospital, have been identified in a low middle-income country.[50] In response, a novel obstetric triage system has been introduced, successfully reducing the delay from arrival at the referral centre to the first assessment by a midwife.[51,52]

Strategies to identify critically ill patients, enable early and appropriate management and thus prevent avoidable critical care admissions, are paramount. These strategies need to be clinically based and not rely on expensive diagnostic modalities, monitoring, and therapeutic options that are mostly not available in RLS.[37,39,43] Poor prioritisation of critical care in RLS may be based on the assumption that it is too expensive when compared with other levels of care.[53] However, good MCC involves relatively inexpensive strategies such as training on how to recognise, respond to and monitor critically ill pregnant patients, and how to target early interventions and prevent acute clinical decompensation. Simple interventions that are known to be effective and inexpensive include: early resuscitation with fluids and antibiotics in sepsis,[36,54] intravenous magnesium sulphate for treatment and prevention of eclampsia, antihypertensive drugs for severe hypertension,[55] the use of uterotonics for the prevention of postpartum haemorrhage (PPH) during the third stage of labour for all births,[56,57] early administration of tranexamic acid to women with postpartum haemorrhage,[58] transportation to a higher level of care, and administration of antenatal corticosteroids.[59] Therefore, a key step in the implementation of good MCC in RLS is increasing the number and skill level of staff. Two important deficiencies in the provision of such MCC include personnel and training, and availability of equipment.[60]

### Personnel and training

Most RLS have severe deficiencies in staffing. Both doctors and nurses are in short supply, and non-physicians provide the vast majority of health care in RLS.[61] The WHO has identified more than 57 countries with critical health professional shortages.[62] Task shifting and empowering staff, such as nurses, to initiate certain treatments with the appearance of signs of physiological deterioration before diagnosis or physician evaluation, may have a positive impact.[61,62]

The CERTAIN (Checklist for Early Recognition and Treatment of Acute Illness) investigators group performed a 22-item capacity and needs assessment survey in 13 critical care units in LMICs. Ten of these units listed "lack of trained staff" as the most important barrier to improving the care and outcomes of critically ill patients.[63]

Training in RLS should prioritise competencies over acquisition of simple factual knowledge. Many training programs are currently dominated by didactic lectures that fail to offer valuable bedside training on clinical

management of patients. These formal teaching methods should be complemented by virtual modalities such as massive open online courses (MOOCs) or online teaching tools. Unfortunately, few MOOCs are available in languages other than English, and most were created in HICs.[64] A World Bank report states that in LMICs, more people have access to cellular telephones than toilets.[65] These telephones and other information and communication technologies are increasingly recognised as powerful, indispensable global health tools, and connect healthcare workers who can share experience and information, and obtain assistance with patient management. One hundred and thirty-five web-based education resources exist for critical care education in a variety of e-learning formats, such as tutorials, self-directed learning modules, interactive case studies, webcasts, podcasts, and video-enhanced programs.[66] Many scientific societies and non-profit organisations are increasingly providing educational sources and financial support to RLS, and most of their certified courses and outreach programmes on critically ill obstetric patients are being made available throughout these regions (Table 5).[67,68] Teamwork training in combination with clinical teaching of technical and non-technical skills, and the use of low cost simulators in high fidelity environments, are crucial components of such courses. It is also appropriate for practitioners to visit centres with a high volume of obstetric patients for training sessions, to acquire and maintain skills.[67,68]

Use of protocols, care bundles and checklists are additional useful tools that can provide direction for clinical decision-making, particularly in the absence of specialists.[69] This approach is particularly well suited to settings where health workers tend to have fewer years of training, less access to specialised diagnostic and monitoring tools and specialist-trained doctors. The CERTAIN initiative mentioned previously uses electronic checklist and decision support tools to facilitate the best practices during admission/resuscitation and daily management of critically ill patients.[63,70] As in all fields of skill development, the risk to institutions and potential benefit to trainees in critical care is that trainees can use newly acquired skills to move to the more desirable urban areas and/or higher paying posts.[60]

## Equipment and supplies

Perhaps the most intimidating feature of critical care in RLS is the recognised need for technology. These needs fall into the following categories: cardiopulmonary monitoring, monitoring of oxygenation and ventilation, support services, and the development of new technologies designed for RLS.

With all electrical equipment, the risks of power supply interruption and power surges are high, necessitating reliable back-up generators and high-capacity surge protectors. Each area of patient care should also include access to a stethoscope, manual blood pressure measurement device, and self-inflating bag-valve-mask resuscitator, for instances of equipment failure and power supply interruption. Equipment is only valuable to the extent that it can be maintained and repaired.[60] This concept of investing in a consistent model, for which both the parts and biomedical technical expertise are available, applies to all technology. For example, a supply of oxygen can be provided by cylinders. Although bulky and expensive, these do not require electricity. Oxygen concentrators are cheaper, but require electricity and may be difficult to maintain over several years. While piped oxygen may be ideal, it requires expensive underlying infrastructure. Maintaining ventilators may be aided by focussing on one model and availability of parts, while ventilator breathing circuits must be durable and multiple-use, and require adequate sterilisation protocols. It would be interesting to extrapolate the World Federation of Societies of Anaesthesiologists (WFSA) strategy of global availability of a pulse oximeter in every operating room, to the critical care unit or any

**Table 5 Obstetric and neonatal emergency courses available in low-resource settings**

| Course | Institutions/Partnerships |
|---|---|
| Safer Anaesthesia from Education (SAFE) obstetrics and paediatrics course | Association of Anaesthetists of Great Britain and Ireland (AAGBI)<br>World Federation of Societies of Anaesthesiologists (WFSA) |
| Essential Steps in the Management of Obstetric Emergencies (ESMOE) | Liverpool School of Tropical Medicine (LSTM)<br>Royal College of Obstetricians and Gynaecologists (RCOG)<br>World Health Organization (WHO)<br>University of Pretoria, South Africa |
| Global Advanced life support in obstetrics. (Global ALSO) | American Academy of Family Physicians (AAFP) |
| Colapso Materno | Latin American Society of Anesthesia (CLASA)<br>Latin American Society of Obstetrics and Gynecology (FLASOG) |
| Emergency Obstetric Care for Doctors and Midwives | JHPIEGO/Averting Maternal Death and Disability Program/Bill & Melinda Gates Foundation |
| Helping Mothers Survive Initiative | Laerdal global health/JHPIEGO |
| PRONTO training programs | PRONTO International |

place outside the operating room in RLS, and in this way have greater availability of pulse oximetry for care of critically ill patients.[71] Basic laboratory capabilities including full blood count, measurement of electrolyte levels, and in some cases blood gases analysis and culture, are critical and raise the level of care for the entire hospital. Technological advancement now enables point-of-care machines to provide a wide array of these tests at reasonable prices, without the need for expensive laboratories and additional staff. Radiology and ultrasound capabilities also raise the overall level of care, with point-of-care ultrasound becoming increasingly more popular as an integral, relatively inexpensive, reproducible point-of-critical care management tool. Supply kits (packaged supplies targeting patient, healthcare provider or health facility requirements) have been proposed to be a simple and low-cost intervention that can address various challenges routinely encountered in RLS.[72] In the area of maternal and newborn health, supply kits have been designed to focus on issues ranging from timely availability of effective treatment in emergency situations and avoidance of stock-outs for routine care.[73]

Leligdowicz and colleagues have recently published the results from their critical care unit resource assessment survey in RLS. The study results highlight which resources are not readily available and are needed in these countries.[74] A list of resources which require development in these areas include blood products, essential equipment such non-invasive ventilation and intra-arterial and central venous catheters, isolation facilities, and access to dialysis.

## Innovation and development of new technologies designed for resource limited settings

The Microlife® CRADLE (Community blood pressure monitoring in Rural Africa and Asia: Detection of underLying pre-Eclampsia and shock) Vital Signs Alert (VSA) is a hand-held, upper-arm, semi-automated device measuring blood pressure and heart rate. The device has been validated in pregnancy, including in hypotensive women and preeclampsia. The monitor meets the WHO criteria for RLS, being robust and portable, requiring minimal calibration, having low power requirements (charging through a micro-USB port), and being affordable, at 25 US dollars per unit. The CRADLE VSA has been further modified, incorporating a traffic light early warning system aiming to alert health care workers and untrained users to vital sign abnormalities. Although the current model of the CRADLE VSA does not have mobile health (mHealth) capabilities, incorporation of mHealth technology into future models is feasible, allowing for transmission of vital signs data from the device to mobile phones or directly to a central facility.[75]

PIERS on the Move (PotM) is a low-cost, easy-to-use, mHealth app that has been developed to aid health workers in making decisions on management of women with preeclampsia. This app is based on a decision model that combines accurate risk prediction of maternal adverse outcomes associated with preeclampsia (miniPIERS), with WHO recommendations for the management of preeclampsia. The PotM app uses an integrated pulse oximetry sensor, the phone oximeter, which allows integrated measurement of oxygen saturation, a vital sign demonstrated to have significant association with risk of adverse outcomes in women with preeclampsia.[76]

### The "virtual" obstetrics intensive care unit

Leovic et al. have proposed an innovative model of care in which a virtual intensive care unit team, composed of pre-selected specialists from multiple disciplines (maternal-fetal medicine, intensivists, cardiologists, pulmonologists, anaesthesiologists, obstetric and critical care nurses, respiratory therapists, and clinical pharmacologists) participate in the provision of individualised care that is readily adapted to the specific patient's clinical needs, regardless of the setting.[77,78] With the help of telemedicine this concept can be applied in RLS, allowing timely assessment and support for primary care health workers.[79] Although this is a proven success in countries such as Australia, it must be remembered that the initial financial outlay for appropriate hardware and internet connections is considerable. New, inexpensive alternatives need to be developed for this to be adopted on a large scale in RLS.

### Blood-delivering drones

Improving access to healthcare is a particular challenge in LMICs. New and innovative ideas are required to reach remote areas. In obstetrics, a major contributor to maternal mortality remains haemorrhage and the lack of access to blood products. Recently, projects have demonstrated the utility of drones in the delivery of blood products to remote areas.[80] This innovative idea may possibly be used for delivery of other medical supplies and, together with telemedicine, may help to overcome the barriers of inhospitable environments.

### Solar powered oxygen delivery

Although on the WHO lists oxygen is an essential medicine, it is not available in many hospitals in LMICs. In a survey of 12 low-income countries, only 44% of 231 health centres had access to oxygen on a continuous basis. In RLS, compressed oxygen cylinders and oxygen concentrators are commonly used. Oxygen cylinders are ready to use and do not require any electricity, however their availability may be compromised by weak stock management, the need for transportation from supplier to hospital, and leakage from ill-fitting regulators.

Oxygen concentrators generate oxygen on site from ambient air. Concentrators overcome the logistical supply barriers of cylinder oxygen, require minimal service and maintenance, and are more user friendly than cylinders. However, oxygen concentrators require a continuous and reliable source of electricity. New ways to deliver oxygen could improve outcomes and save numerous lives where oxygen cylinders are not widely available and electrical power is not reliable. A novel strategy, solar powered oxygen delivery, which concentrates oxygen from ambient air using solar energy, is currently under evaluation. The potential energy efficiency, low cost and ease of use make solar power an attractive field of investigation for use in RLS.[81–83]

## Conclusion

"Maternal Critical Care" describes the interdisciplinary care of any pregnant patient, according to the severity of their medical condition, regardless of the location in a hospital. There are many challenges facing health workers in RLS, such as lack of drugs, equipment, supporting infrastructure, and trained personnel, inadequate transportation as well as late and severe presentations of disease. In order to improve MCC, training programmes should embrace modern technological educational aids. Also, strategies should be adopted that incorporate new tools and technologies allowing for the prediction of critical illness in the pregnant patient. Bedside assessment tools, such as early warning scores, may be useful to identify critically ill patients and those at risk of deterioration. The goal must be for improved outcomes following early interventions, early initiation of resuscitation, and early transfer to an appropriate level of care. Importantly, the political will must exist in RLS to enable appropriate funding for the necessary infrastructure to enable training of healthcare workers and transfer of critically ill women to units with adequate obstetric, anaesthesia, intensive and neonatal care.

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## Conflicts of interest

There are no conflicts of interest.

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