Maternal high-care and intensive care units in low- and middle-income countries

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Highlights

- Global disparities are evident in maternal intensive care provisions.
- Limited-resource settings face challenges with resources and training.
- Targeted resource distribution and staff training in maternal critical care are crucial.
- Prompt and expert care can mitigate severe obstetric complications.
- Unified efforts in advancing maternity care are essential for better maternal health.

Abstract

Despite notable advancements in minimizing maternal mortality during recent decades, a pronounced disparity persists between high-income nations and low-to middle-income countries (LMICs), particularly in intensive and high-care for pregnant and postpartum individuals. This divergence is multifactorial and influenced by factors such as the availability and accessibility of community-based maternity healthcare services, the quality of preventive care, timeliness in accessing hospital or critical care, resource availability, and facilities equipped for advanced interventions. Complications from various conditions, including human immunodeficiency virus (HIV), unsafe abortions, puerperal sepsis, and, notably, the COVID-19 pandemic, intensify the complexity of these challenges. In confronting these challenges and deliberating on potential solutions, we hope to contribute to the ongoing discourse around maternal healthcare in LMICs, ultimately striving toward an equitable health landscape where every mother, regardless of geographic location or socioeconomic status, has access to the care they require and deserve. The use of traditional and innovative methods to achieve adequate knowledge, appropriate skills, location of applicable resources, and strong leadership is essential. By implementing and enhancing these strategies, limited-resource settings can optimize the available resources to promptly recognize the severity of illness in obstetric individuals, ensuring timely and appropriate interventions for mothers and children. Additionally, strategies that could significantly improve the situation include increased investment in healthcare infrastructure, effective resource management, enhanced supply chain efficiency, and the development and use of low-cost, high-quality equipment.

Through targeted investments, innovations, efficient resource management, and international cooperation, it is possible to ensure that every maternal high-care and ICU unit, regardless of geographical location or socioeconomic status, has access to high-quality critical care to provide life-saving care.

Keywords: Maternal mortality; Obstetrics; Critical care; Low- and middle-income countries (LMICs)

1. Introduction

Maternal health, a vital component of public health, faces unique obstacles in low- and middle-income countries (LMICs) due to social, economic, and healthcare system-related factors. Despite notable advancements in minimizing maternal mortality in recent decades, a pronounced disparity persists between high-income nations and LMICs, particularly in intensive and high care for pregnant and postpartum individuals.

Conventional critical care is typically centralized. However, obstetric intensive care often deviates from this model, and depending on local, cultural, and operational capabilities, critically ill obstetric patients might receive treatment in assorted locations within the hospital [1]. Ninety-nine percent of maternal deaths occur in LMICs, primarily due to hemorrhage, sepsis, hypertensive disorders, and pregnancy complications [[2], [3], [4]].

Amidst the substantial and impactful global health challenges, the term maternal high-care and intensive care units in LMICs appears to be a pivotal yet frequently undervalued concern. In these nations, epidemiological projections indicate that up to 15% of subjects encounter a critical illness during pregnancy. This multifactorial divergence includes the availability and accessibility of community-based maternity healthcare services, the quality of preventive care, timeliness in accessing hospital or critical care, resource availability, and facilities equipped for advanced interventions [5]. While real-time data on this topic are scant, several studies denote a higher incidence of critical care admissions in LMICs than in wealthier regions (0.7 per 1000 births in high-income countries vs. 13.5 per 1000 births in LMIC countries) [6]. Mortality rates in LMICs range from 2 to 43.6 compared to well-resourced regions where mortalities are well below 5% [7].

Complications from HIV, unsafe abortions, puerperal sepsis, and, notably, the COVID-19 pandemic intensify the complexity of these challenges, amplifying the necessity for well-equipped and proficiently staffed high-care and intensive care units capable of managing obstetric emergencies.

This review explores indications that necessitate admission to high-care and intensive care units in obstetric individuals, investigates the nuances of surviving sepsis guidelines, and assesses their feasibility in LMICs. Additionally, we will examine the present status of obstetric high-dependency units (HDUs) and intensive care units (ICUs) in these regions, elucidate strategies for organizing and training healthcare professionals, and explore the availability and necessity of vital equipment. In confronting these challenges and considering potential solutions, we hope to contribute to the ongoing discourse around maternal healthcare in LMICs, ultimately striving toward an equitable health landscape where every mother, regardless of geographic location or socioeconomic status, has access to the care they require and deserve.

This review aims to shed light on the various aspects of this critical issue, facilitating a holistic understanding of the landscape toward sustainable solutions. This review is an invitation to reflect, question, and strategize – for the health of mothers today will shape the world of tomorrow.

2. Indications for ICU admission in maternal healthcare in low- and middle-income countries

Indications of maternal ICU admission are classified as those related directly to pregnancy (i.e., obstetric hemorrhage, hypertensive diseases of pregnancy, puerperal sepsis, thromboembolic phenomena, acute fatty liver), those indirectly related to pregnancy (i.e., disease exacerbations due to pregnancy) and those seemingly coincidental to the pregnant state (e.g., trauma, nonpuerperal sepsis). A summary of potential causes of critical illness with a higher prevalence of LMICs in pregnant individuals is described in Table 1.

Table 1. Causes of critical illness in pregnancy in LMICs.

Causes of critical illness in pregnancy	**Preexisting diseases that may worsen during pregnancy**	**Increased susceptibility during pregnancy**
Directly related to pregnancy	Systemic lupus erythematosus	Pyelonephritis
Severe preeclampsia	Myasthenia Gravis	Pneumonia
Hypertensive crisis	Autoimmune thyroiditis	Pulmonary embolism and Deep vein thrombosis
HELLP	Hypertension	
Eclampsia	Vascular heart diseases	
Abruption/rupture	Pulmonary hypertension	
Uterine inversion	Cardiomyopathies	
Retained products	Arrhythmias (Atrial fibrillation/flutter)	
Adherent placenta	Congenital heart disease	
Obstetric hemorrhage	Cardiogenic pulmonary edema/shock	
Ruptured ectopic	Asthma	
sepsis (chorioamnionitis)	Epilepsy	
Unsafe abortions	Diabetes mellitus	
Endometritis and puerperal sepsis		

In LMICs, where most maternal deaths are largely deemed preventable, the predominant causes include hemorrhage, preeclampsia, sepsis (including human immunodeficiency virus [HIV] and tropical diseases), complications arising during pregnancy, delivery, unsafe abortion practices, and violence [8,9]. However, estimating the reality of this situation is problematic because, in many scenarios, the decision for critical care support is replaced by allocations to perioperative units or high-dependency areas. Many of these conditions require continuous monitoring of vital signs, laboratory samples, images, and perfusion tests that are seldom available in outreach ICU areas.

In LMICs, managing the intersectionality of the global HIV epidemic and pregnancy-related complications necessitates discerning critical care, particularly in the realm of ICU admissions [10]. Pregnant subjects with HIV infection have an increased susceptibility to severe HIV-related complications secondary to infections, requiring management in intensive care, with a higher risk of adverse birth outcomes, such as perinatal complications, including preterm birth and intrauterine growth restriction, and a heightened risk of mother-to-child transmission [11].

The burden of maternal sepsis, defined as an infection developed during or after childbirth, highlights another critical indication for ICU admission. Despite the decline in global maternal mortality rates, sepsis remains a leading cause of maternal death, especially within LMICs and adolescents, where sanitized birthing environments and timely antibiotic treatments may be scarce [12]. Rapid progression of the infection can lead to septic shock, a life-threatening condition necessitating ICU admission. In some places, almost one-quarter of all maternal near-miss cases and one-half of maternal deaths have been attributed to infection, and substandard care has been identified in over one-half of these cases with severe maternal outcomes [13].

Sepsis, secondary to endometritis and unsafe abortion, is another alarming source of maternal morbidity and mortality in LMICs, often leading to severe complications such as hemorrhage, infection, and multiple organ dysfunction [14].

In general, the source of infection leading to sepsis varies according to the cause (obstetrical versus nonobstetrical) and time of appearance (antepartum or postpartum). In this manner, septic abortion and endometritis account for the most obstetrical sources. Postabortion care, particularly for complications from unsafe procedures, may necessitate ICU admission for comprehensive management and recovery [15]. On the other hand, urinary tract infections and pneumonia are the leading sources of nonobstetric sepsis.

Last, the COVID-19 pandemic has presented new and unprecedented challenges for maternal healthcare. SARS-CoV-2 infection during pregnancy increases the risk of maternal death, severe maternal morbidities, and neonatal morbidity [16]. Pregnant individuals with severe COVID-19 symptoms or those developing complications such as preterm labor or preeclampsia due to the infection often require ICU admission. The need for specialized care for pregnant individuals with COVID-19 added complexity to the already strained ICU capacities in LMICs. For instance, different outcomes arise in pregnant individuals with severe COVID-19, including admission to the ICU, receipt of critical care (defined as admitted to the ICU or receiving ventilation or any site-defined indicator), any ventilation use, and clinician-diagnosed pneumonia. In a recent multicountry meta-analysis, including a comprehensive analysis pooling data from 21 studies across 33 countries involving 21,977 pregnancies, the authors identified factors associated with severe COVID-19-related outcomes in pregnant patients and their babies. Key findings reveal that comorbidities (pooled RR 2.55 [95% CI: 1.97–3.31]), nutritional status (pooled RR 1.81 [95% CI: 1.26–2.60]), and older maternal age (35–45 years) (pooled RR 1.60 [95% CI: 1.36–1.89]) significantly increase the risk for severe COVID-19 outcomes, such as ICU admission. Furthermore, the incidence of ICU admission was higher among LMICs such as Africa and Colombia [17].

In LMICs, several factors affect the decision to admit patients to the ICU, ranging from the intensity of health issues to resource availability. Smaller or lower-level facilities (often the first entry point to a healthcare facility in an emergency) are more likely to demonstrate shortages of essential drugs and basic equipment [18], with larger centers exhibiting more variations in care. This discrepancy can be attributed to how administrative, nursing, and provider resources are distributed, which can, in turn, impact clinical care outcomes [19]. Despite these challenges, identifying clear admission indications is a crucial step in improving the quality of maternal healthcare and reducing maternal mortality rates in these regions. Consequently, initiatives must concentrate on criteria standardization, healthcare provider training enhancement, and ensuring timely and effective ICU access for mothers and their babies.

Recognizing the severity of illness in obstetric individuals, especially in limited-resource settings, is crucial for timely intervention and preventing maternal and fetal morbidity and mortality. This early recognition can be achieved through multiple strategies (Fig. 1):

1. Community Engagement and Education [20].

- Educating individuals: Empowering pregnant subjects through knowledge about danger signs, such as severe bleeding, high fever, and persistent vomiting during pregnancy.
- Community health workers: Engage communities in monitoring pregnancy and educating them about the significance of antenatal care and recognizing critical symptoms.

2. Utilizing Low-Resource Diagnostic Techniques [21].

- Physical examination: Basic physical examination skills are used to assess vital signs, such as blood pressure, respiratory rate, and consciousness level, to identify potential risks or abnormalities.
- Basic Laboratory Tests: Even basic tests such as hemoglobin levels, urine protein estimation, and point-of-care infection markers can offer invaluable insights into a subject's health during pregnancy.

3. Implementation of Warning Signs Protocols [22].

- Checklists and Protocols: Employing simplified checklists and protocols that help healthcare workers systematically identify warning signs and facilitate prompt responses.
- Modified Early Obstetric Warning Scores (MEOWS): Adapting and implementing scores such as the MEOWS to detect deterioration in obstetric patients by monitoring vital signs and facilitating early interventions.

4. Telemedicine and Remote Assistance [23].

- Telehealth: Utilizing telemedicine for remote consultations, especially for healthcare workers in rural or isolated areas to consult with specialists in urban centers.
- Remote Monitoring: Employing basic remote monitoring tools wherever possible to keep track of high-risk patients' health parameters.

5. Leveraging Community Resources [24].

- Local Traditional Birth Attendants (TBA): Training and involving the TBA in recognizing the early signs of obstetric complications and ensuring assertive communication with healthcare professionals.
- Community-based interventions: Developing and supporting community-based health programs that facilitate the early recognition of high-risk pregnancies and timely referrals.

6. Building Reference Networks [25].

- Establishing referral pathways: Developing precise and efficient referral routes and processes ensures adequate management for all obstetric complications in facilities with appropriate resources and expertise.
- Transport Solutions: Find feasible solutions, such as community-driven transport options, to ensure that pregnant or postpartum individuals can reach healthcare facilities during emergencies.

7. Focused Training for Health Workers [26].

- Scenario-based Training: Engaging healthcare workers in scenario-based training that enhances their skills in recognizing and managing obstetric emergencies.
- Continuous Professional Development: Ensuring that health workers can access ongoing training and skill enhancement opportunities, even in low-resource settings.

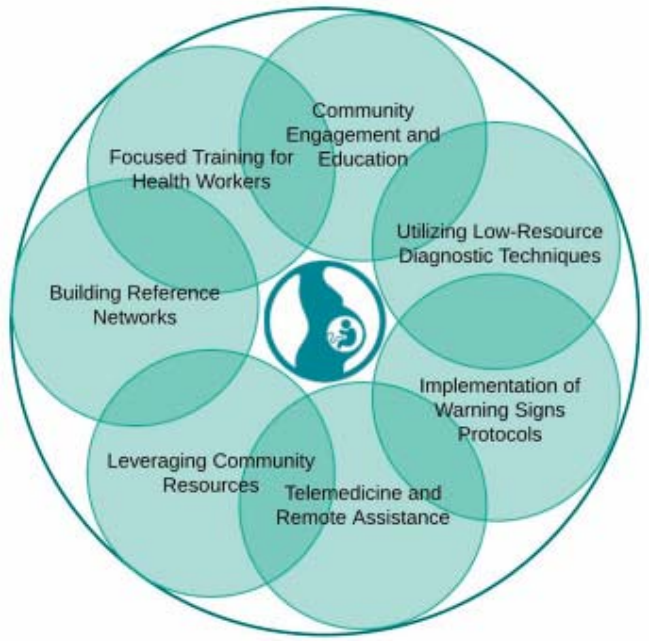

Fig. 1. Strategies for early recognition of severity of illness in low-resource settings.

By implementing and enhancing these strategies, limited-resource settings can optimize the available resources to recognize the severity of illness in obstetric individuals promptly, ensuring timely and appropriate interventions to safeguard the health of both mothers and children.

3. Surviving sepsis guidelines

Infections, especially sepsis, present a pronounced risk in LMICs, substantially contributing to increased morbidity and mortality rates [27]. This issue is exacerbated by challenges such as inadequate preventative measures, delayed access to healthcare, and less-than-optimal sepsis management practices [28].

The Surviving Sepsis Campaign (SSC) guidelines are a notable initiative designed to reduce mortality from sepsis by providing comprehensive management protocols, particularly for well-resourced countries [29]. This guideline comprehensively addresses the early recognition of sepsis, early initiation of antimicrobial therapy, and monitoring. The guidelines provide a framework of essential considerations in managing adult patients with sepsis or septic shock. However, acknowledging the guideline's limitations in LMIC contexts and for specific populations, such as pregnant individuals, is vital. Moreover, the guidelines predominantly derive from trials within well-resourced settings, inadvertently obscuring LMIC-specific challenges. Illustratively, research from Kenya [30] and Zambia [31] in 2014 and 2017 indicates that fluid boluses, which might be beneficial in well-resourced settings, can prove detrimental in LMICs. This situation highlights the need for trials in LMICs to validate findings observed in well-resourced regions before extrapolating in such regions. The rapid administration of fixed doses of fluid, particularly in the face of variable aetiologies, and the absence of vasopressors or mechanical ventilation can be catastrophic. It emphasizes the need for individualized fluid management (volume and rate of administration) based on the underlying cause, therapy response, and resource availability.

The SSC guidelines draw recommendations from data on managing gram-positive and gram-negative bacterial sepsis. Meanwhile, in LMICs, sepsis is also linked to conditions such as enteric fever, malaria, and viral hemorrhagic fevers, each demanding distinct therapeutic approaches [32]. This disparity emphasizes that recommendations of empirical antimicrobial choice and therapy duration might not universally apply, especially considering LMIC-specific infectious diseases.

The most recent SSC guidelines attempt to factor in issues related to LMICs. Nevertheless, resource availability is highly variable in LMICs, with essential agents such as vasopressors, mechanical ventilators, arterial blood gas analysis, and organ support therapy unavailable or temporarily out of stock. The high prevalence of antimicrobial resistance and the lack of availability of various antimicrobial choices also preclude effective therapy. These factors may account for the lack of uptake of the SSC guidelines, which may be challenging to implement in LMICs. As such, LMICs need to scale and adapt the principles of SSC to their local environment until local studies are available to better inform local evidence-based guidelines. These adaptations should include sepsis recognition and the importance of early antimicrobials.

One notable limitation arises from the absence of pregnant patients in numerous interventional trials, resulting in the guidelines not explicitly addressing maternal sepsis. As such, monitoring the cardiorespiratory response to therapy needs to consider the physiological changes of pregnancy. The physiological alterations during pregnancy, including the notable immunological modifications, complicate the recognition of sepsis and impact the immunological response to it, underlining a critical need for guidelines centered around obstetric sepsis.

The recognition of sepsis in pregnancy is commonly delayed, given that tachycardia and tachypnoea may be attributed to the gravid state. Additionally, the expanded intravascular volume accompanying pregnancy may mask the hypovolemia of sepsis, potentially delaying diagnosis until the patient is nearing shock. Furthermore, a decline in blood pressure during the second trimester might be mistakenly considered a normal physiological response. The effectiveness of pregnancy-specific warning systems, such as the Sepsis in Obstetrics Score (SOS), Obstetrics modified quick SOFA Score, and Modified Obstetric Early Warning System

(MOEWS), must be evaluated at a local level for their utility in discerning infections, given the absence of a universally recognized best tool for doing so in pregnancy [33].

Sepsis in obstetric guidelines should include a sepsis screening tool, evaluation of organ dysfunction and severity of illness, the importance of early therapy (airway, breathing, circulation) including early empiric antimicrobials, the need for aggressive source control, appropriate fluid (determining requirement, type, volume and how to monitor response and when to stop) appropriate investigations and organ support. These guidelines should also include monitoring the pregnant subject's response to therapy to inform whether to stop treatment, escalate therapy, or refer a patient for additional therapy.

4. Availability of obstetric high dependency units and intensive care units in low- and middle-income countries

Discrepancies in Access to Specialized Obstetric Care in LMICs: In assessing the resilience and readiness of a healthcare system, we must examine its access to and availability of specialized obstetric Care – precisely, HDU and ICUs [34]. Regrettably, within the sphere of LMICs, the current landscape of these units reveals evident gaps and challenges that urgently call for innovative and proactive solutions [35].

Diverse Availability across Regions: The presence and number of obstetric HDUs and ICUs vary widely among LMICs. Reports suggest that ICU bed availability per 100,000 population in Limpopo and the Western Cape in South Africa oscillates between 0.7 and 5 [36]. In contrast, Belgium and Germany report much higher figures, with 21.9 and 24.6 ICU beds per 100,000 population [37]. Factors such as financial limitations, an inadequate pool of trained healthcare staff, and infrastructure deficiencies have left certain regions without these facilities [38]. Inadequate referral systems and inefficient transport systems influence the course of care.

Urban–Rural Dichotomy: Beyond regional disparities, there is a pronounced urban–rural inequity in the distribution of these units. With their superior infrastructure and resources, urban areas unsurprisingly harbor more specialized units. This situation is worrying, considering that a significant portion of the population in many LMICs lives in rural areas, hence highlighting a critical inequity in healthcare access [35].

Challenges in Care Quality: Even when HDUs and ICUs are available, the quality of care remains a substantial concern. A deficit of trained healthcare professionals, combined with an erratic supply of essential equipment and medicines, weakens the efficacy of these units [39]. The inconsistent implementation of standardized protocols for enhancing patient outcomes further exacerbates this challenge.

The COVID-19 Pandemic and its Impact on Obstetric Units: The COVID-19 pandemic has exacerbated preexisting limitations in critical care resources, particularly affecting obstetric units, which were transformed to treat critically ill COVID-19 patients [40]. This burden exposed the precarious existing system and punctuated the imperative for scalable and sustainable solutions. For example, the African COVID-19 Critical Care Outcomes Study (ACCCOS), encompassing ten countries and 64 hospitals (primarily tertiary), unveiled substantial resource constraints in numerous African nations, including inconsistencies in oxygen availability (47% of hospitals), pulse oximetry provision (86%), renal replacement therapy (68%), and significant restrictions in admitting critical care referrals [41].

Strategies to Address Resource Gaps: Confronting these challenges necessitates a multifaceted approach. Initial steps involve substantial financial investments in healthcare infrastructure, with an emphasis on expanding obstetric HDUs and ICUs in rural and underserved areas through the construction and upgrading of facilities and ensuring the consistent availability of essential equipment and medications.

In parallel, prioritizing human resources is critical. This requisite encompasses recruiting and retaining skilled healthcare professionals in these specialized units and a continual investment in their training and professional development. Utilizing telemedicine and mobile health technologies may also mitigate shortages of specialized staff, especially in isolated and rural regions [42].

Moreover, establishing and implementing standardized, context-specific protocols and guidelines for patient management in obstetric HDUs and ICUs, accounting for the unique challenges and constraints of LMICs, is vital.

Importance of Research and Future Directions: Research focusing on maternal critical Care in LMICs is indispensable to defining policy and practice. The scarcity of data regarding the availability, utilization, and outcomes of obstetric HDUs and ICUs hampers efforts to enhance these facilities [38].

In conclusion, although the present scenario of obstetric HDU and ICU availability in LMICs presents a sobering picture, targeted interventions, sustained investments, and innovative solutions can significantly improve this landscape. The goal must remain clear: every woman, irrespective of where she lives, deserves access to quality critical care when needed.

5. Organizing and training healthcare professionals

Obstetric emergencies can escalate very rapidly, ending in serious adverse outcomes for the pregnant patient or the fetus, including death. The outcomes of critically ill patients mainly focus on the early recognition of illness by the identification of warning signals, appropriate interventions to stabilize the patient, timely referral, safe transfer, appropriate monitoring, and the institution of best-practice medical management throughout the continuum of care. Delays in appropriate treatment are known to adversely impact patient outcomes. Thus, all healthcare professionals managing obstetric patients need adequate training to recognize illness, implement emergency care, and safely transfer.

Strategies to improve knowledge and address skills shortages include the following (Table 2):

1. Training initiatives

- Training health workers (midwives, community health workers, medical interns, and medical officers) to recognize and manage obstetric emergencies and preventative medicine. The successful ESMOE (Essential Steps in Managing Obstetric Emergencies) program in South Africa demonstrates the potential of investing in such programs [43].
- Use of telemedicine to support health care professionals both for training and "on-demand "assistance."
- Simulation training can enhance clinical upskilling and decision-making.
- Basic and advanced workshop training or regular refresher courses

2. Mentorship programs to support health care professionals to assist with the translation of training into clinical practice.

3. Collaborations with educational institutions, both local and international organizations, as well as the private sector, are essential to facilitate training and improve clinical service delivery.

Table 2. Strategies to improve knowledge and address skills shortages.

1. Training initiatives • Training health workers to recognize and manage obstetric emergencies and preventative medicine. • Use of telemedicine. • Simulation training. • Basic and advanced workshop training. 2. Mentorship programs. 3. Collaborations with educational institutions.
The needs mentioned above are to be complemented by: • Community engagement - training and public education regarding early illness recognition. • Access to essentials includes equipment, fluids, and necessary drugs. • Implementation of locally relevant guidelines/safety checklists. • Engagement with health policymakers. • Electronic registries.

The needs mentioned above are to be complemented by.

1. Community engagement - training and public education regarding early illness recognition to avoid delayed presentations. Building trust is essential; training programs must be culturally sensitive and familiar with local childbirth-related customs.
2. Access to essentials includes equipment, fluids, and necessary drugs (including antimicrobials, vasopressors, oxygen, and antihypertensive agents).
3. Implementation of locally relevant guidelines/safety checklists to improve patient outcomes.
4. Engagement with health policymakers to enable effective health delivery by addressing needs (infrastructure, resources, communication, transport)
5. Electronic registries are in place to facilitate data collection.

Ideally, critically ill obstetric patients require admission to a specialized intensive care unit (ICU) and be managed by a critical care subspecialist (intensivist) who leads the multidisciplinary team. In LMICs, ICU and high-care beds are exceptional, and intensivists are scarce even in the ICU setting. Thus, the patient may require critical care management in the general ward setting by clinicians managing the obstetric emergency.

In such cases, strategies to achieve adequate management outreach in the ICU include offering regular refresher courses for clinicians and nurses, Diplomas in Critical Care, telemedicine

support from experienced centers (locally and internationally), simulation training, collaborative support from academic institutions, and the availability of mentorship.

Resource limitations for offering organ support to critically ill patients remain a reality in LMICs. Thus, a pragmatic approach designed to identify local needs with the input of experts and stakeholders is critical. Considering the variations observed across different geographic locations, a needs assessment would be helpful to determine appropriate solutions.

Incorporating a "train the trainer" approach by investing in "instructor courses" would ensure the sustainability of solutions. Investing in such approaches may also identify barriers such as internet connectivity, infrastructure limitations, language barriers, and equipment shortages, which can be addressed. Overcoming these barriers requires communication and continuous working with healthcare policymakers.

6. Equipment availability in obstetric high-care and intensive care units in low- and middle-income countries

Guidelines from the Critical Care Society of Southern Africa (CCSSA) categorize critical care units into varying levels, each with specific equipment and monitoring capacities: High Care Units (HCUs) and Level 1–3 Intensive Care Units (ICUs). High-care units (HCUs) and Level 1 ICUs should offer basic monitoring (continuous ECG, respiratory rate, SpO 2, invasive and noninvasive blood pressure, urine output, glucose, temperature, airway, and neurological monitoring, including GCS) [44].

Single-organ support, other than mechanical ventilation, should be available. This support includes supplemental oxygen therapy, inotrope/vasopressor support, parenteral antihypertensives, renal replacement therapy (RRT), plasma exchange, airway support, and external ventricular drain monitoring and drainage. Noninvasive ventilation (NIV) or high-flow nasal cannula (HFNC) therapy may be offered when available.

A Level 2 ICU usually refers to an ICU at a regional hospital level led by an intensivist. It additionally provides intermittent or continuous monitoring (arterial pressure, intra-abdominal pressure, arterial blood gas analysis) and invasive and noninvasive mechanical ventilation.

Level 3 ICUs are in a tertiary public hospital. Level 3 ICUs offer modern, specialized critical care to complex critically ill patients.

Additional monitoring includes advanced cardiac output monitoring, continuous capnography, echocardiography, and neuromonitoring. Other therapies offered include extracorporeal membrane oxygenation (ECMO). The Critical Care Society of Southern Africa also outlines the staffing (nursing and medical) and equipment requirements for critical care services in South Africa.

Obstetric HDUs and ICUs are pivotal in maternal healthcare, acting as the nexus between specialized care and favorable maternal outcomes. The equipment's presence, such as ventilators, infusion pumps, and an adequate stock of essential medications, is inherently tied to survival and recovery, especially in high-risk cases. However, in LMICs, resource limitations often obstruct the pathway, notably in vital equipment and pharmaceuticals, often resulting in compromised care and suboptimal outcomes [38].

The gap between LMICs and high-income countries in equipment availability is substantial. The deficiency of life-saving devices and stable medication supply lines, including essentials such as ventilators, infusion pumps, monitors, and necessities such as beds and clean linen, are often insufficient or poorly maintained [45]. The shortage of necessary drugs (e.g., antibiotics and uterotonics) not only limits the quality of care but also escalates the risk of detrimental maternal outcomes [46].

The COVID-19 pandemic has exacerbated this situation. Global demand for ventilators, medications, and personal protective equipment (PPE) has strained supply chain shortages and led to sharp price increases, making these items even less accessible for LMICs [47]. The relocation of obstetric units to provide attention to COVID-19 patients has also further strained the already limited resources available for maternal care [48].

Addressing these issues requires multiple approaches. First, it is essential to increase investment in healthcare infrastructure and equipment. Governments, international donors, and private sector partners must collaborate to finance essential equipment and improve storage and maintenance facilities [49].

Second, strategies to optimize the use of existing resources should be implemented. Adopting the "ICU without borders" concept [50] and implementing equipment sharing or leasing models stands out as a creative approach, ensuring that even amidst limitations, essential healthcare services remain accessible. By incorporating robust training programs for healthcare workers focused on effective equipment utilization and routine maintenance, the durability and functionality of existing equipment can be significantly enhanced.

Third, enhancing the efficiency of supply chains through improved projecting equipment and medication needs, refining processes, and establishing effective inventory management systems to ensure consistent and reliable availability of necessary resources.

Last, promoting and incorporating low-cost, high-quality equipment by developing and applying innovative solutions further presents a viable route. The advent of low-cost ventilators [51,52] and manual vacuum aspiration kits for managing postabortion complications [53] exemplifies how innovation can bridge the gap between resource scarcity and healthcare delivery.

Pandemic-induced challenges have ironically opened the door to positive strides, such as the heightened production of ventilators and the highlighted importance of resilient health systems, which might witness increased investments and refinements in the future [54].

Finally, in the realm of technological solutions, the evolution and application of 3D printing (3DP) technologies extend an innovative avenue to transcend the barriers of resource limitations, ensuring the availability of specialized medical devices without reliance on extensive supply chains. It fosters a culture of global collaboration by enabling the sharing of digital models, which professionals can assess and print [55].

In conclusion, while the pathway to establishing fully equipped obstetric high-care and ICU units in LMICs is burdened with difficulties, through targeted investments, innovations, efficient resource management, and international cooperation, it is possible to ensure that every maternal high-care and ICU unit is well equipped to provide life-saving care. The strategies and solutions described in this section guide the possibilities that arise when innovation,

strategy, and collective will converge toward a unified, vital goal: safeguarding maternal lives in critical conditions.

7. Summary

Maternal high-care and intensive care units (ICUs) serve as a cornerstone in managing obstetric emergencies, significantly influencing the quality of maternal healthcare, especially in low- and middle-income countries (LMICs). This review has identified and analysed vital facets that govern the efficiency and effectiveness of these units in LMICs, offering essential insights into the existing landscape and the urgent changes needed to enhance maternal care outcomes.

Indications for ICU admission, such as complications from HIV, unsafe abortions, puerperal sepsis, and COVID-19, highlight the intricate and varied maternal health challenges that these units address. The widespread disparities in infrastructure, resources, and capacity significantly compromise the quality and accessibility of critical maternal Care in LMICs. The COVID-19 pandemic has further strained these already limited resources, illuminating the urgent need for scalable and sustainable solutions. Nonetheless, it has also triggered an increased production of ventilators and other essential equipment, which may hold potential for improved equipment availability in the long run.

The overarching implication for maternal healthcare in LMICs is clear: targeted interventions, sustained investments, and innovative solutions are urgently needed to bridge the gaps in the system. Increased investment in healthcare infrastructure, efficient resource management, enhanced supply chain efficiency, and the development and use of low-cost, high-quality equipment are among the strategies that could significantly improve the landscape.

Furthermore, the underreporting or absence of reporting on core outcomes, as identified in the review, calls for improved research methodologies and more comprehensive data collection mechanisms in these settings. A more complete understanding of both core and noncore outcomes will inform policy and practice, guiding the allocation of resources toward areas of greatest need and potential impact.

In conclusion, while the challenges are significant, the goal is within reach. By prioritizing maternal health and acting on the insights gained from this review and others like it, we can ensure that all individuals, regardless of their geographical location or socioeconomic status, have access to the high-quality critical care they need. The path forward requires collaboration and determination, but the reward – a world where no woman dies from preventable causes related to pregnancy and childbirth – is undoubtedly worth the effort.

Practice points

- There is a pronounced disparity between high-income nations and LMICs in intensive and high-care service provision and outcomes for pregnant and postpartum individuals.
- Various health issues, including HIV, unsafe abortions, puerperal sepsis, and, notably, the COVID-19 pandemic, amplify the necessity for well-equipped and proficiently staffed high-care and intensive care units capable of managing obstetric emergencies.
- Solutions need to incorporate needs assessments in terms of resources and enablers.
- The use of traditional and innovative methods to achieve adequate knowledge, appropriate skills, location of applicable resources, and strong leadership is essential.

- Targeted investments, innovations, efficient resource management, and international cooperation are essential to ensure that every maternal high-care and ICU unit is well equipped to provide life-saving care.

Research agenda

A potential research agenda, including the main topics described in this chapter, must include:

- Assessment of Healthcare Infrastructure.
- Efficacy of various training programs and partnerships in improving clinical service delivery and emergency responsiveness in obstetric care.
- Analysis of the impact of geographic and socioeconomic factors on access to high-quality maternal care.
- Research and develop low-cost, high-quality medical devices and equipment tailored to LMICs.
- Conduct longitudinal studies to understand the long-term outcomes for mothers and children who receive ICU care, including physical, psychological, and social aspects.

This agenda addresses the complexities and diversities in maternal health needs, focusing on evidence-based interventions and systemic changes to improve outcomes for mothers in low- and middle-income countries.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used Grammarly to enhance readability and clarity. After using this tool/service, the author(s) reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

JAS and FP have no conflicts of interest to declare.

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