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NARRATIVE REVIEW

A health systems approach to critical care delivery in low-resource settings: a narrative review

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Abstract

There is a high burden of critical illness in low-income countries (LICs), adding pressure to already strained health systems. Over the next decade, the need for critical care is expected to grow due to ageing populations with increasing medical complexity; limited access to primary care; climate change; natural disasters; and conflict. In 2019, the 72nd World Health Assembly emphasised that an essential part of universal health coverage is improved access to effective emergency and critical care and to "ensure the timely and effective delivery of life-saving health care services to those in need". In this narrative review, we examine critical care capacity building in LICs from a health systems perspective. We conducted a systematic literature search, using the World Heath Organisation (WHO) health systems framework to structure findings within six core components or "building blocks": (1) service delivery; (2) health workforce; (3) health information systems; (4) access to essential medicines and equipment; (5) financing; and (6) leadership and governance. We provide recommendations using this framework, derived from the literature identified in our review. These recommendations are useful for policy makers, health service researchers and healthcare workers to inform critical care capacity building in low-resource settings.

Keywords: Critical care, Low income countries, Health systems, Capacity building

Introduction

The most effective way of building critical care capacity in low-income countries (LICs) is not currently known [1]. LICs, defined by the World Bank as countries with a gross national income pro capite of < $1045 per year, are home to 700 million people, equating to 9% of the world's population [2]. People living in the 28 LICs (23 of which are in sub-Saharan Africa) suffer a substantial burden of critical illness [3, 4], over four times higher than in high-income countries (HICs) [5]. Three-quarters of deaths from pneumonia, meningitis and other infections [6] and almost 90% of trauma deaths [7] and obstetric complications [8] occur in LICs. Traumatic injury is an increasingly common presentation requiring critical care in LICs [9, 10]. As populations age, the emerging syndemic of acute (e.g. malaria) and chronic (e.g., tubercolosis and human immunodeficiency virus) communicable and non-communicable diseases in LICs is adding a considerable burden to already strained health systems [5, 11].

The recent coronavirus disease 2019 (COVID-19) pandemic highlighted the global disparity of critical care

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services [11–15], especially in sub-Saharan Africa, where there is commonly less than one bed per 100,000 population [15]. There are particular concerns in socio-politically volatile low-income countries such as Yemen [14], Afghanistan [16], Somalia [17] and Sudan [18]. Over the past decade in particular, it has been increasingly argued that critical care in low-resource settings should be prioritised [19]. There are contextual differences in healthcare systems between LICs and high-income countries (HICs) that must be considered when designing appropriate models of critical care for resource-constrained settings [20, 21].

In this narrative review, we explore the current evidence for critical care delivery in LICs through a health systems lens. We employ the World Health Organization (WHO) Health Systems Framework [22], structured using six core components or "building blocks" (see methods section), to examine critical care capacity building within LIC health systems. Within critical care, essential services should be prioritised and provided before expanding coverage of lower-priority services, in-line with the ethical principles of equity and benefit maximization [23]. Our aim in using these approaches is to highlight pragmatic actionable recommendations to effectively build critical care capacity in low-resource settings.

Methods

We conducted a systematic literature search using terms shown in Box 1 (details provided in supplementary file 1). Studies were included if they described the provision of care for critically or severely ill adults, in any hospital setting. Exclusion criteria: studies reporting only from high- or middle-income countries; neonatal care; paediatric care; military-based studies; and pre-hospital care. Paediatric and neonatal studies were excluded as our focus was adult care. A search of MEDLINE on 17 November 2022 identified a total of 1086 articles that were screened by at least two authors (BM, SS, DOH) by title and abstract. We identified 231 full manuscripts potentially suitable for inclusion and made these available to all authors for consideration. We selected 80 full manuscripts for the review (see Fig. 1) [1, 4, 5, 8–14, 16, 17, 20, 21, 24–89]. Additional articles were identified from reference lists within included studies and author experience [2, 3, 6, 7, 15, 18, 19, 22, 23, 90–152]. We have included a reflexivity statement [90] describing how we have promoted equity in our research partnership and promoted a broad range of expert perspectives (supplementary file 2).

Take-home message

There is an urgent need to increase critical care capacity in low-income countries to meet the needs of vulnerable patients. We provide recommendations through a health systems lens to design and develop context-sensitive critical care services in low-income countries. Strategies to objectively prioritise how critical care services should be provided within the wider healthcare system are urgently required.

Box 1: Search strategy. World Bank Fiscal Year 2022 [150]. The full strategy is included in the manuscript appendix

Key terms: "critical illness" AND "low income country" AND NOT "paediatric" OR "neonatal".

Critical illness search: (critical* OR sever*) AND (ill* or unwell) OR organ failure OR intensive care ICU OR intensive therapy OR ITU OR critical care OR emergency care OR acute care.

Low income country search: (Low$ or poor$) adj2 (income or resource) adj2 (setting or countr*) OR low$income OR resource$restricted OR LIC OR resource$poor OR (all low income countries as defined by the World Bank 2022 Fiscal Year listed individually).

We have structured this narrative review according to the WHO framework that describes health systems in terms of six core components or "building blocks": (1) service delivery; (2) health workforce; (3) health information systems; (4) access to essential medicines; (5) financing; and (6) leadership/governance [22]. This relatively simple framework facilitates a common language for policy makers, health service researchers and healthcare workers and is used frequently within health systems research on capacity building [91]. Subsequently, we formulated recommendations structured within this framework, synthesised from included manuscripts and agreed between the authorship team. We did not use formal tools such as GRADE (Grading of Recommendations, Assessment, Development, and Evaluations) to develop and present summaries of evidence for this limited narrative synthesis. In addition, whilst all authors agreed on our formulated recommendations within the WHO "building blocks" framework, we did not employ a formal Delphi process to develop consensus on these.

Definitions

For the purpose of this review, critical illness is defined as "a state of ill health with vital organ dysfunction; a high risk of imminent death without treatment; and the potential for reversibility" [92]. We use the term "low resource settings" synonymously with healthcare

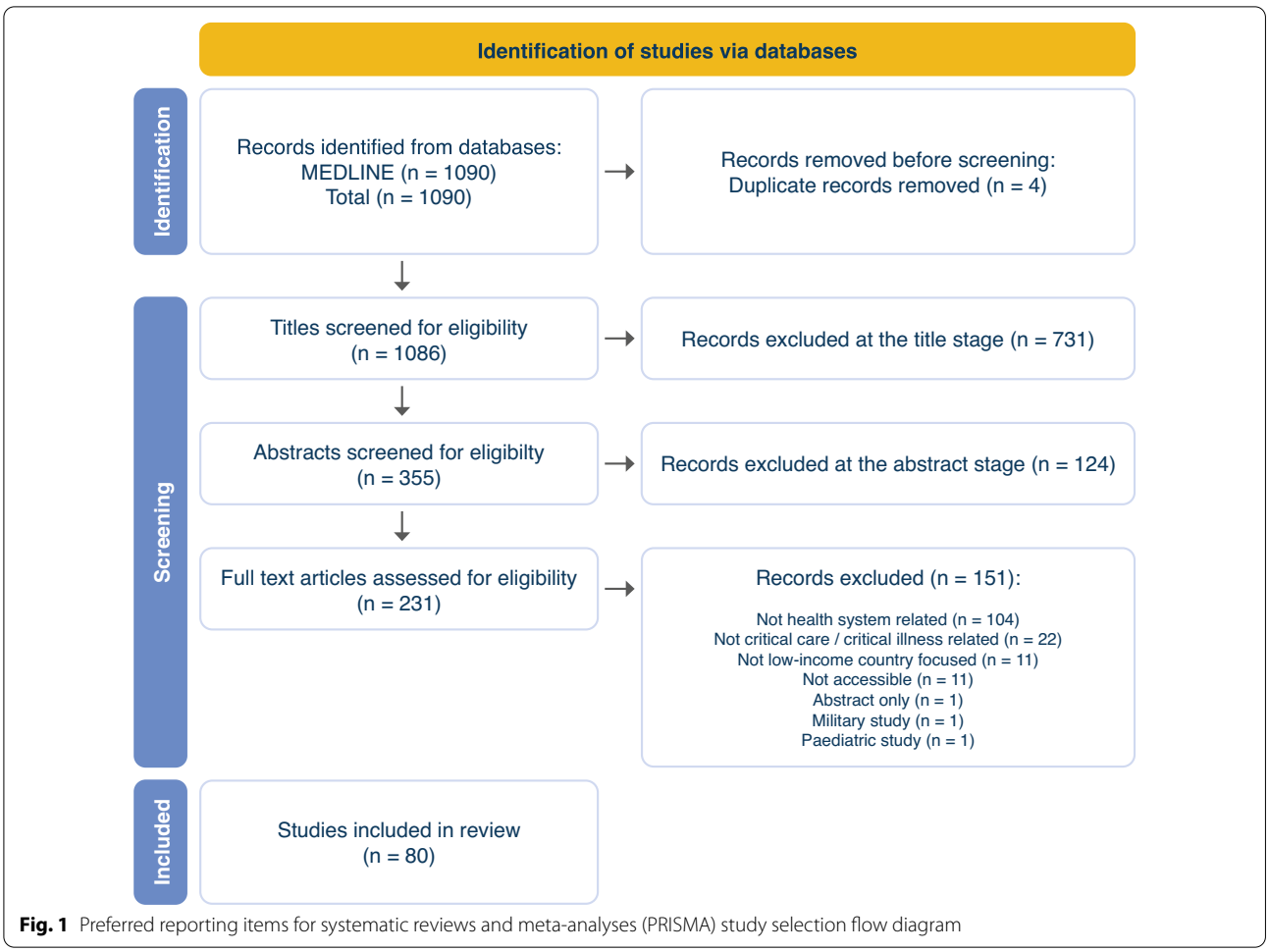

Fig. 1 Preferred reporting items for systematic reviews and meta-analyses (PRISMA) study selection flow diagram

provided in LICs for this review. Patients with critical illness may require different levels of critical care ranging from "enhanced" (level 1, e.g., increased monitoring) to "basic organ support" (level 2, e.g., isolated vasopressors) and "advanced organ support" (level 3, e.g., mechanical ventilation). The United Kingdom (UK) Intensive Care Society has recently produced an updated framework to describe levels of care, aligned to recommended staffing ratios required for patients with critical illness [93]. Whilst we concentrate on these definitions for this review, alternative guidance is available [94–96]. There is no universal model of critical care delivery, however, such that healthcare provision for patients with critical illness differs between settings. As stakeholders from LICs seek to increase critical care provision, health systems frameworks are required to facilitate the development of effective and sustainable context-sensitive models of delivery to meet the needs of local populations [11].

Health service delivery

Access to critical care is unevenly distributed throughout the world. For example, within Africa, Uganda has 0.1 and South Africa 6.0 advanced critical care beds (equipped to provide mechanical ventilation) per 100,000 population [15]. Within countries there are also wide variations, particularly between under-served rural areas and comparatively well-resourced urban areas [36, 97]; and between the public and private sectors [11, 98]. In LICs, people suffer from a greater burden of critical illness than in HIC and middle-income countries (MIC) (47,728 disability-adjusted life years (DALYs) per 100,000 population in LICs vs. 25,186 per 100,000 in MICs vs. 15,681 per 100,000 in HICs) [4]. However, utilisation of emergency and critical care is lower (8 visits per 1000 population in LICs vs 78 in MICs vs 264 in HICs [4]) due to limited access and capacity within services. Expansion of robust and accessible critical care (when needed) is a pressing issue in LICs where there is an ageing population with increasing medical complexity; insufficient access to primary care; and increased risk of natural disasters

and conflict [8]. Appropriate selection of patients for advanced care with life-threatening but reversible pathology is vital to leverage existing scarce resources for population benefit [25, 99]. However, guiding ethical principles for admission are not always observed [74], and selection may sometimes be based on implicit, non-transparent criteria, other than clinical need [100].

Reported outcomes for dedicated critical care units in LICs are variable, dependent on location and case-mix. A large, observational cohort study of patients admitted to critical care with severe COVID-19 across Africa showed a mechanical ventilation rate of 40% and a mortality of 47% (rising to 79% in those who required ventilation) [101]. Further, there are reported mortality rates of 67% and 58% for patients requiring mechanical ventilation in Ethiopia [24] and Sudan [85], respectively. Outcomes for patients with critical illness who do not require ventilation are poorly defined in LICs but is likely to be high; for example, mortality for critically ill obstetric patients in Rwanda was 54% [102]. A prioritisation setting exercise recently identified barriers to care (including patient pathways through the emergency care system); implementation of patient registries; and impact of triage systems as three of the seven highest-ranking emergency care research questions in low- and middle-income countries [69]. In addition, patient perspectives have been used to inform the development of improved acute care pathways in Ghana [103].

The WHO Emergency, Trauma and Acute Care programme include tools to support the development of quality and timely emergency care [104]. Whilst not specific to critical care, the African Federation for Emergency Medicine has developed and piloted the Emergency Care Assessment Tool (ECAT) to identify gaps in service delivery and readiness to facilitate targeted development of capacity [33]. In addition, the Interagency Integrated Triage Tool has been tested in Papua New Guinea to improve patient triage, flow and data management for emergency presentations [105]. Multiple resource assessment tools targeted toward critical care have also been developed and piloted in low-income settings [36, 38, 41, 43, 68, 70, 84, 106]. The WHO Quick Check tool designed to rapidly identify patients with severe illness in low-income settings has been evaluated in Uganda [46]. The essential emergency and critical care framework have subsequently been developed to define the key minimum constituents of care required for patients with critical illness [19]. The aim of this approach is to promote simple, effective and low-cost measures nested within existing hospital healthcare systems; this is aligned with initiatives such as the "Kampala declaration on sepsis" [79] and the "three delays" model for severe sepsis in resource-limited settings [107].

Successful health service delivery is contingent on addressing all health system building blocks. However, there are multiple challenges, including low staff training levels; lack of essential equipment; and prohibitive out-of-pocket expenses [11, 29, 108] discussed further below. There are concerns that direct transplantation of critical care delivery models developed in high-income settings may neither be effective nor sustainable in lower-resourced settings [20, 50]. For example, the place of fluid resuscitation as part of treatment algorithms for septic shock is unclear in this context [28, 58, 109]. A foundational approach of increasing access to supportive critical care (level 1 and 2 care through the lens of UK provision [93]) whilst building workforce expertise promotes sustainability and facilitates stakeholder-driven design of higher-level services for local populations [11, 20]. Acute kidney injury requiring renal replacement therapy, for example, has been managed with acute peritoneal dialysis (as a cheaper alternative to haemodialysis) in Tanzania [110].

Healthcare workforce

Low-income countries, particularly those in sub-Saharan Africa, are more likely to suffer critical shortages of healthcare workers (threshold 23 per 10,000 population per WHO definition) compared to high-income countries [111]. There are 0.3 physicians per 1000 population in low-income countries compared to 3.7/1000 in high-income countries [112]. Countries in Africa, for example, carry 22% of the global burden of disease but only employ 3% of the healthcare workforce [113]. These regional issues are compounded by inequitable distribution at the local level, with marked disparities in critical care provision between urban and rural settings [11, 34]. At the hospital level, the lack of critical care workforce capacity impacts other specialties. In Addis Ababa (Ethiopia) for example, patients who met the criteria for critical care admission were frequently cared for in the emergency department, which resulted in reduced patient flow and compromised patient safety [86]. In Ghana, a lack of critical care specialists means that critically ill patients are frequently managed by junior medical staff with no formal residency training [114].

An advanced critical care bed is operational only if there is sufficient and adequately trained staff available. A large survey exploring critical care delivery in Asian intensive care units (ICUs) between 2013–2014 found fewer certified intensivists and lower rates of life support training in lower-income countries compared to high- and middle-income Asian countries [115]. In Ethiopia, care by junior nursing staff and poor staffing ratios were associated with an increased risk of unplanned extubation [76] and an increased risk of adverse events [31].

Here, nurses report high levels of anxiety [39] and back pain, [87] and doctors face significant challenges dealing with resource scarcity [48]. Similarly, critical care nurses in Ethiopia, Malawi and Uganda have reported a lack of appropriate training, insufficient workforce and high workloads [44, 51–54, 66, 71, 72, 75, 77, 78]. These issues are associated with negative impacts on patient care, patient safety and implementation of evidence-based practice [37, 42].

Kwizera et al. have documented how the Ugandan government and key stakeholders co-ordinated an increase in critical care capacity in response to the COVID-19 pandemic [11]. Here, the authors applied a critical care capacity-building framework to evaluate critical care provision within the health system nationally, including the assessment of skilled human resources. This exercise highlighted inadequate training provision for both doctors and nurses; poor renumeration; and lack of pathways for career progression. Medium- and long-term measures to increase critical care capacity described by this group may be generalisable in low-income settings post-pandemic. For example: (1) partnership development with high-income countries to develop context-sensitive training opportunities [56]; (2) provision of dedicated salaried posts for critical care nurses and doctors as a recognised sub-specialty; and (3) creation of a unifying body to promote cohesion and leadership to improve standards nationally. Postgraduate critical care training programmes have been described for nurses, doctors and physiotherapists in multiple LICs [40, 59, 73, 82, 83, 88, 89]. Investment in this training, including paths for professional growth and leadership, could promote sustainability with formal accreditation to develop a skilled critical care workforce [49, 52, 60, 116]. A further consideration is whether task-shifting initiatives, for example enhanced training for anaesthetic clinical officers, may help to address staffing requirements [21]. The inherent tension between the need for highly skilled healthcare workers to manage patients with critical illness and addressing the needs of the wider health system requires high-level strategic direction from policy makers, with particular focus on staff retention [49].

Health information systems

Integrated health information systems (HIS), enabling a secure flow of data to end users, are an essential component of critical care practice, used to drive quality improvement; benchmark practice; and underpin research activities [65, 117]. There are, however, multiple challenges to the successful implementation of critical care HIS in LICs. These include a lack of essential infrastructure [50, 57]; inadequate governance to promote data reliability [35, 118], including reliance on manual data entry [119]; limited interoperability with existing local HIS [45, 80]; and insufficient national and sub-national stakeholder engagement, compromising accessibility, usability and effectiveness [120].

Co-creation of key quality indicators for data collection, informed by local stakeholders including healthcare workers and patients, is an important precursor to drive engagement with, and implementation of, critical care HIS [119]. Critical care HIS should be nested within local organisational structures and daily care processes [121]. Further, there must be careful consideration of how human resources are deployed when collecting registry data to promote reliability and mitigate against the risk of impaired clinical provision [121]. Data management systems to ensure quality control and quality assurance as part of robust governance processes are also required.

The Critical Care Asia HIS is a cloud-based platform built through a collaborative partnership between 97 critical care units in Afghanistan, Bangladesh, India, Malaysia, Nepal, Pakistan and Vietnam [45, 122]. This HIS employs a setting-adapted data platform with a common data model, enabling interrogation of locally-driven research priorities and data sharing. There is now work underway (since 2020) to implement across nine African countries, six of which are LICs [123]. This platform has facilitated the operationalisation of the multinational Randomized, Embedded, Multifactorial Adaptive Platform Trial for Community-Acquired Pneumonia (REMAP-CAP) trial in India, Nepal and Pakistan, an embedded adaptive trial to generate context-relevant data to guide optimal management strategies for patients with severe community-acquired pneumonia [124]. Whilst individual registry HIS modules have been developed in single centres [20], partnership with established international registries such as the Critical Care Asia collaboration is more likely to be a sustainable solution for emerging critical care units (across the continuum of enhanced to advanced care) in LICs.

Access to essential medicines and equipment

Effective critical care delivery requires appropriate serviced equipment and uninterrupted supplies of medicines and consumables. Agreement on what constitutes a core item (e.g., equipment, consumables and drugs) must be done at both national and facility level. The WHO Essential Medicines List provides guidance on which medications are safe, effective and cost effective to health systems [125, 126], with additional emergency guidance provided during COVID-19 [127]. Expert groups have defined 213 medicines as essential or desirable for emergency medicine practice, stratified by facility level and clinical indication [128]. Oxygen, however, was only been designated as an essential medicine as

recently as 2017 [129]. Many countries further refine pharmacopoeias, from which individual facilities should select and ensure day-to-day provision. Analogous systems for medical equipment are more poorly developed, leading to patchy and unpredictable implementation. However, established key evidence-based solutions, such as capnography, have potential for considerable positive impact in individual ICUs and operating theatres in LICs [61]. Larger-scale equipment infrastructure, such as oxygen ecosystems, require national strategies, and long-term financing across the entire critical care network (see below).

Surveys in several low-resource sub-Saharan countries have found a lack of essential equipment, disposable materials and medications (oxygen, vasopressors, sedatives, antibiotics) as frequent barriers to the provision of effective critical care [63, 64, 68, 106, 114]. Complex and parallel logistical pathways and financial limitations contribute to long supply times and chronic shortages of core items [130]. Particularly at-risk are treatments for specific and infrequent clinical indications, including life-saving antidotes, such as anti-tetanus immunoglobulin, snake antivenom and rabies vaccine [4], as well as product-specific consumables and components required for equipment repair (e.g., oxygen concentrators [131]). Of particular concern is the lack of provision for analgesic and palliative medications [132]. Top-down procurement and a lack of planning and feedback from end-users in facilities exacerbates this. Potential solutions include: using evidence-based policies (to justify selection); coordination and harmonization of purchasing informed by cost-effectiveness (to improve cost-efficiency) [133]; introduction of national health insurance schemes (to reduce burdensome and potentially devastating out-of-pocket expenses to patients); and strengthening local and regional production (seen most recently in COVID-19 therapeutic manufacturing [134]).

Essential equipment and consumables required for critical care delivery have been defined [19]. Although equipment is available in some hospitals [36], the infrastructure and expertise for maintenance and repair are frequently lacking as is training for effective use [26]. For example, a survey across 15 ICUs in Ethiopia found that 80% of units had blood gas analysers but only one had the reagents needed [68]. A lack of technological solutions is frequently cited by staff as a major limitation in care [135], but such investments may also lead to complacency and detract from the basic quality of care. For example, adherence to ventilator-associated pneumonia care bundles was patchy in a Syrian implementation project [27] and compliance with WHO hand hygiene guidelines low in Ethiopia [32]. Improving data systems to allow an audit of use, and to link usage with re-ordering is possible and impactful in LICs [136]. Procurement of medicines and equipment must therefore take into account the capability and training needs of the critical care environment to safely use them, prioritizing high-quality essential patient care [137].

Health systems financing

In 2019 the United Nations (UN) General Assembly committed to accelerating efforts toward the achievement of Universal Health Coverage (UHC) and reaffirmed commitment to increasing health financing in support of this. UHC means that all individuals and communities should receive the health services they need, without suffering financial hardship [138]. While the global political commitment to UHC is welcome and important, public funding is yet to match what is needed to deliver on this. Out-of-pocket payments are frequently high, compromising equitable access to critical care, resulting in catastrophic health care costs with poor outcomes. Irrespective of funding, critical care can become unaffordable when high-cost interventions are used indiscriminately, or when associated with complications. Maximising critical care service efficiency, for example through patient cohorting and improved staff training (see above), is essential. Some commentators have advocated to shift health system financing away from specialist, hospital-based services, toward community, first-level serviced delivery platforms [139]. This position rests on the argument that hospital care is less cost-effective and thus should be de-prioritised. Whilst this may be true for services that can be delivered in either hospital or community/first-level platforms, when services can *only* be delivered through hospitals (such as critical care), this position does not necessarily hold.

Economic evaluation is increasingly being used to inform the package of interventions that should be covered by health insurance schemes in LICs [97, 140, 141]. However, policy decisions made to maximise the societal health gain for a given expenditure may conflict with direct clinical goals of maximising health gain for individual patients [142]. Disease-specific DALYs are frequently used to inform healthcare policy agenda setting [143]. Given the range of diseases that may cause critical illness, multidisciplinary specialists need to collaborate and agree on definitions and measures of critical illness-associated DALY burden [8]. Development of robust economic methods is required to identify critical care interventions that meet normative thresholds of cost-effectiveness in LICs.

Assuming engagement, resource and expertise to commission economic evaluations to inform critical care

scale-up in LICs, there are multiple methodological challenges that need to be addressed. These include heterogeneous patient cohorts; treatment practice; health systems contexts; input prices; and outcomes [30]. This implies the need for large (expensive) studies risking a lack of generalisability between and within countries where the threshold for cost/quality-adjusted life-year (QALY) gained should be set [81]. Furthermore, capturing the longer-term impacts on patients during recovery from critical illness requires follow-up periods beyond those in most trials [144].

Whilst the Disease Control Priorities project [145] highlighted multiple examples of cost-effective individual emergency care services in LICs, the cost-effectiveness of emergency care delivered across the health system is a key research question yet to be addressed [62, 69]. The scope of this work needs to capture critical care delivered for patients across the spectrum of critical illness, not limited to ventilator-equipped critical care locations or specific conditions [47, 81, 146, 147]. Conceptualisation and explanation of the spectrum of critical care delivery within secondary health care systems are essential for effective policy engagement [97]. We recommend context-sensitive economic evaluations of critical care models (rather than specific interventions) in LICs such as recent work conducted in Tanzania [148]. Partnership with healthcare providers who offer critical care services to understand contextualised costing models is a pragmatic way to approach this issue. Models should be founded on understanding where and how critical care is delivered, to whom, and with what resources within the local health system. Critically, these evaluations should be used to understand how to expand and improve that capacity without adversely affecting the delivery of other health interventions.

Leadership and governance

Critical care provision requires political will at the subnational, national and international levels. The COVID-19 pandemic exposed this lack of resources cruelly. Countries were urgently forced to choose between strategies of prevention and treatment in settings without vaccines or effective treatments. Low-resource countries generally first focused on prevention, whilst building capacity for care delivery, including vital oxygen provision [134]. The experience of COVID-19 has allowed hospitals to plan and practice managing cohort wards and isolation areas, including escalation and de-escalation of care.

Once political will to increase critical care capacity has been achieved, care for critically ill patients requires sound decision-making and governance. Decisions in the choice and design of critical care health systems should include frameworks to provide a sustainable service, in accordance with WHO health system building blocks [22]. The 72nd World Health Assembly regarding emergency care provision in low-resource settings (Resolution 72.16), described the specific need for governance, processes and protocols to support emergency care in hospital settings, including policies for sustainable funding [149]. For example, poor adherence to infection prevention and control policies increases the burden of multidrug resistant infections, complicating the management of patients with critical illness and decreasing cost-effectiveness. Reports from Tanzania, Sierra Leone and Malawi reveal limited availability of such protocols and guidelines, even in larger central and referral hospitals [36, 43, 67]. For example, a survey in Malawi found that only 33.3% of hospitals had guidelines to deliver emergency or critical care [63].

Recently, governments in Ethiopia, Malawi and Tanzania have recognised the need to improve and integrate emergency and critical care into existing health systems to progress towards Universal Health Coverage targets [55, 63, 97, 149]. Development of guidelines for patient admission requires the adoption of local medico-legal; ethical; and socio-cultural norms relating to appropriate escalation and withdrawal of life-sustaining interventions and/or palliation if continued treatment is not beneficial. There is often strong social pressure applied to physicians with decision-making power to limited critical care resources. This debate is importantly focused on making appropriate care available for all, including those receiving palliation for terminal illness.

Limitations

This narrative synthesis has several limitations. Due to a lack of supporting resources, we were unable to employ systematic processes (such as GRADE recommendations and/or Delphi consensus) to formulate our recommendations. Instead, we extracted salient, critical care specific recommendations from included studies, structured using WHO health system building blocks. Further, we were unable to include patient perspectives within the review process. Most manuscripts included in this review were conducted in sub-Saharan Africa, reflective of where the majority of LICs are situated; studies from Papua New Guinea, Afghanistan, Yemen and Syria are also represented. Our search strategy included manuscripts indexed in MEDLINE only. We did not include manuscripts that explored critical care capacity-increasing initiatives pertinent to middle-income countries within this review. Therefore, whilst we describe some strategies that have been tried in MIC contexts (e.g. patient engagement on service provision in Ghana), we are unable to systematically address which

Table 1 Recommendations

Building block	Recommendations	Examples
Health service delivery	Research is required to understand the burden of critical illness to understand epidemiology; outcomes; and impact on health care delivery in LICs Development of context-specific knowledge is essential to drive relevant and appropriate clinical approaches	The National Institute for Health and Care Research (NIHR) Global Health Research Portfolio funds high-quality applied health research and training in areas of unmet need [151]
Healthcare workforce	Integration of healthcare worker postgraduate critical care training within national Ministry of Health programmes to promote formal accreditation and recognition of the specialty Designation of critical care as a specialty service with the provision of dedicated positions to promote staff retention	Multisectoral and multidisciplinary partnership to build critical care capacity in Uganda, inclusive of measures to improve workforce training and retention [11]
Health information systems	Customize existing critical care health information systems for local users to drive quality improvement (QI) Key to successful implementation is equitable data access for relevant stakeholders to monitor resource utilization and patient outcomes	The Collaboration for Research, Training and Implementation in Critical Care in Asia and Africa (CCAA) aims to develop a data research hub to drive locally led research and QI [152]
Access to essential medicines and equipment	Prioritisation of equipment, consumables and drugs using evidence-based policies informed by tools developed during the COVID-19 pandemic Coordination between national and facility levels on what constitutes core treatment items for inclusion within updated national-level standard treatment guidelines	Multiple guidelines are available to guide clinicians and policymakers in this area [19, 126–128] Multisectoral partnership to address COVID-19 in Uganda agreed and implemented priority medicines and equipment [11]
Health systems financing	Develop and apply health economic analyses to measure critical care illness-associated DALY burden estimates and estimate cost-effectiveness of critical care services to inform policymakers Prioritise inclusion of critical care within health insurance and health finance plans to deliver universal health coverage and reduce the risk of catastrophic costs	Cost-utility analysis of high dependency unit obstetric care in Sierra Leone [146] Incremental cost analysis of "essential emergency and critical care" in Tanzania [148]
Leadership and governance	Foster multidisciplinary national and regional critical care associations to allow effort-saving collaborations, development of local leaders and context-appropriate policies and guidelines Develop locally endorsed admission guidelines, and SOPs for critical care wards	Partnership between the WHO and the Ethiopian Ministry of Health to support the delivery of national priorities for enhanced emergency care provision [55]

MIC interventions may be suitable for application in LIC contexts. In addition, we excluded neonatal and paediatric studies in our search strategy. Children and adults are sometimes cared for together within the same critical care areas in low incomes settings such that this restriction may have excluded some relevant citations. Further, there remains a paucity of evidence that explicitly explore facilitators and barriers to the implementation of critical care capacity-building measures in low-income countries. Further research is required to delineate critical care-specific issues and solutions from generic constraints across the wider health system.

Summary

We have employed a health systems framework to examine critical care capacity building in LICs, structured using the WHO six "building blocks" approach [22]. From a healthcare delivery (block 1) perspective, we identified multiple tools inclusive of clear guidelines and checklists pertinent to critical care in low-income settings, with examples of successful pilots. However, care for critically ill patients who do not require ventilation is not well described in low-income settings representing a key gap in our understanding of optimal service delivery. Healthcare workforce (block 2) training and retention of a skilled critical care workforce are key priorities for sustainable and safe services. Application of a critical care capacity-building framework in Uganda highlighted multiple recommendations, including leverage of existing partnerships to build context-relevant training programmes. Also needed is explicit recognition and provision of critical care by the Ministry of Health, including speciality specific salaried positions. From a health information systems (block 3) perspective, critical care-specific healthcare setting adaptive platforms are now being rolled out in multiple low-income countries. Recent examples of successful delivery on multinational trials using these platforms highlights the potential to develop contextually relevant data to drive improved outcomes. Access to essential medicines and

equipment (block 4) remains a key limitation due to high capital expenditure and operating costs (maintenance, consumables and drugs). This means critical care provision is extremely vulnerable to interruptions in supplies and funding. Solutions proposed to mitigate these risks are interdependent with health financing and effective leadership and governance. From a health financing perspective (block 5), transparent methods are required to underpin trade-offs that are required to fund critical care services and build capacity within the wider health system. The lack of robust health economic approaches represents a key limitation to the prioritisation and expansion of cost-effective critical care services in low-income settings. From a leadership and governance perspective (block 6), we found evidence of increasing political will to prioritise critical care services in low-income countries. However, at the sub-national level, we identified both a lack of- and low adherence to- critical care relevant policies and guidelines. Based on our findings we have formulated recommendations structured using the building blocks framework (see Table 1).

Supplementary Information
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Declarations

Conflicts of interest
No conflicts of interest are declared.

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References

1. Touray S, Sanyang B (2019) Critical care in sub-Saharan Africa: is it ready for prime time? Ann Am Thorac Soc 16:156–157
2. Bank TW (2023) World Bank Open Data. https://data.worldbank.org/. Accessed 10 Apr 2023
3. Dünser MW, Baelani I, Ganbold L (2006) A review and analysis of intensive care medicine in the least developed countries. Crit Care Med 34:1234–1242
4. Chang CY, Abujaber S, Reynolds TA, Camargo CA Jr, Obermeyer Z (2016) Burden of emergency conditions and emergency care usage: new estimates from 40 countries. Emerg Med J 33:794–800
5. Razzak J, Usmani MF, Bhutta ZA (2019) Global, regional and national burden of emergency medical diseases using specific emergency disease indicators: analysis of the 2015 Global Burden of Disease Study. BMJ Glob Health 4:e000733
6. Cheng AC, West TE, Limmathurotsakul D, Peacock SJ (2008) Strategies to reduce mortality from bacterial sepsis in adults in developing countries. PLoS Med 5:e175
7. Mock C, Kobusingye O, Joshipura M, Nguyen S, Arreola-Risa C (2005) Strengthening trauma and critical care globally. Curr Opin Crit Care 11:568–575
8. Adhikari NKJ, Fowler RA, Bhagwanjee S, Rubenfeld GD (2010) Critical care and the global burden of critical illness in adults. Lancet 376:1339–1346
9. Luggya TS, Ngabirano AA, Richardson S, Osire J, Achieng L, Nabulime J, Mabweijano J (2021) Trauma unit management and outcomes at an urban tertiary hospital in sub-Saharan Africa: a descriptive study. Afr Health Sci 21:1794–1800
10. Brown MW, Foy KE, Chanda C, Mulundika J, Koralnik IJ, Siddiqi OK (2018) Neurologic illness in Zambia: a neurointensivist's experience. J Neurol Sci 385:140–143
11. Kwizera A, Sendagire C, Kamuntu Y, Rutayisire M, Nakibuuka J, Muwanguzi PA, Alenyo-Ngabirano A, Kyobe-Bosa H, Olaro C (2022) Building critical care capacity in a low-income country. Crit Care Clin 38:747–759

12. Sonenthal PD, Masiye J, Kasomekera N, Marsh RH, Wroe EB, Scott KW, Li R, Murray MB, Bukhman A, Connolly E, Minyaliwa T, Katete M, Banda G, Nyirenda M, Rouhani SA (2020) COVID-19 preparedness in Malawi: a national facility-based critical care assessment. Lancet Glob Health 8:e890–e892
13. Elhadi M, Msherghi A, Alkeelani M, Alsuyihili A, Khaled A, Buzreg A, Boughididah T, Abukhashem M, Alhashimi A, Khel S, Gaffaz R, Ben Saleim N, Bahroun S, Elharb A, Eisay M, Alnafati N, Almiqlash B, Biala M, Alghanai E (2020) Concerns for low-resource countries, with under-prepared intensive care units, facing the COVID-19 pandemic. Infect Dis Health 25:227–232
14. Lee JS, Godard A (2020) Critical care for COVID-19 during a humanitarian crisis-lessons learnt from Yemen. Crit Care 24:572
15. Ayebale E, Kassebaum N, Roche A, Biccard B (2020) Africa's critical care capacity before COVID-19. South Afr J Anaesth Analg 26:162–164
16. Shah J, Essar MY, Qaderi S, Rackimuthu S, Nawaz FA, Qaderi F, Shah A (2022) Respiratory health and critical care concerns in Afghanistan. Lancet Respir Med 10:229–231
17. Ali MM, Malik MR, Ahmed AY, Bashir AM, Mohamed A, Abdi A, Obtel M (2022) Survival analysis of all critically ill patients with COVID-19 admitted to the main hospital in Mogadishu, Somalia, 30 March-12 June 2020: which interventions are proving effective in fragile states? Int J Infect Dis 114:202–209
18. Dyer O (2023) Sudan's health system is "beyond collapse" as hospitals are directly targeted in fighting. BMJ (Clin Res Ed) 381:p939
19. Schell CO, Khalid K, Wharton-Smith A, Oliwa J, Sawe HR, Roy N, Sanga A, Marshall JC, Rylance J, Hanson C, Kayambankadzanja RK, Wallis LA, Jirwe M, Baker T (2021) Essential emergency and critical care: a consensus among global clinical experts. BMJ Glob Health 6:e006585
20. Morton B, Banda NP, Nsomba E, Ngoliwa C, Antoine S, Gondwe J, Limbani F, Henrion MYR, Chirombo J, Baker T, Kamalo P, Phiri C, Masamba L, Phiri T, Mallewa J, Mwandumba HC, Mndolo KS, Gordon S, Rylance J (2020) Establishment of a high-dependency unit in Malawi. BMJ Glob Health 5:e004041
21. Towey RM, Ojara S (2007) Intensive care in the developing world. Anaesthesia 62(Suppl 1):32–37
22. WHO (2010) Monitoring the building blocks of health systems: a handbook of indicators and their measurement strategies. WHO
23. WHO (2014) Making fair choices on the path to universal health coverage. https://www.who.int/publications/i/item/9789241507158. Accessed 01 June 2023
24. Abate SM, Assen S, Yinges M, Basu B (2021) Survival and predictors of mortality among patients admitted to the intensive care units in southern Ethiopia: a multi-center cohort study. Ann Med Surg (Lond) 65:102318
25. Abdalrahman IB, Elgenaid SN, Babiker Ahmed MA (2021) Use of intensive care unit priority model in directing intensive care unit admission in Sudan: a prospective cross-sectional study. Int J Crit Illn Inj Sci 11:9–13
26. Alkubati SA, Al-Sayaghi KM, Alrubaiee GG, Hamid MA, Saleh KA, Al-Qalah T, Al-Sadi AK (2022) Adherence of critical care nurses to endotracheal suctioning guidelines: a cross-sectional study. BMC Nurs 21:312
27. Alsadat R, Al-Bardan H, Mazloum MN, Shamah AA, Eltayeb MF, Marie A, Dakkak A, Naes O, Esber F, Betelmal I, Kherallah M (2012) Use of ventilator associated pneumonia bundle and statistical process control chart to decrease VAP rate in Syria. Avicenna J Med 2:79–83
28. Andrews B, Muchemwa L, Kelly P, Lakhi S, Heimburger DC, Bernard GR (2014) Simplified severe sepsis protocol: a randomized controlled trial of modified early goal-directed therapy in Zambia. Crit Care Med 42:2315–2324
29. Andualem H, Beyene T, Tuli W (2022) Knowledge and practice about Glasgow Coma Scale assessment among nurses working in adult intensive care units of federal public hospitals in Addis Ababa, Ethiopia: a cross-sectional study, Ethiopia. J Health Sci 32:895–904
30. Arabi YM, Phua J, Koh Y, Du B, Faruq MO, Nishimura M, Fang WF, Gomersall C, Al Rahma HN, Tamim H, Al-Dorzi HM, Al-Hameed FM, Adhikari NK, Sadat M (2016) Structure, organization, and delivery of critical care in Asian ICUs. Crit Care Med 44:e940-948
31. Assaye AM, Wiechula R, Schultz TJ, Feo R (2022) Missed nursing care, nurse staffing levels and patient safety outcomes in low-income country acute care settings: An observational study. Int J Nurs Pract 28:e13031
32. Awoke N, Geda B, Arba A, Tekalign T, Paulos K (2018) Nurses practice of hand hygiene in Hiwot Fana specialized university hospital, Harari regional state, Eastern Ethiopia: observational study. Nurs Res Pract 2018:2654947
33. Bae C, Pigoga JL, Cox M, Hollong B, Kalanzi J, Abbas G, Wallis LA, Calvello Hynes EJ (2018) Evaluating emergency care capacity in Africa: an iterative, multicountry refinement of the Emergency Care Assessment Tool. BMJ Glob Health 3:e001138
34. Baker T, Khalid K, Acicbe O, McGloughlin S, Amin P (2017) Critical care of tropical disease in low income countries: report from the Task Force on Tropical Diseases by the World Federation of Societies of Intensive and Critical Care Medicine. J Crit Care 42:351–354
35. Baker T (2009) Critical care in low-income countries. Trop Med Int Health 14:143–148
36. Baker T, Lugazia E, Eriksen J, Mwafongo V, Irestedt L, Konrad D (2013) Emergency and critical care services in Tanzania: a survey of ten hospitals. BMC Health Serv Res 13:140
37. Banda Z, Simbota M, Mula C (2022) Nurses' perceptions on the effects of high nursing workload on patient care in an intensive care unit of a referral hospital in Malawi: a qualitative study. BMC Nurs 21:136
38. Barkley AS, Spece LJ, Barros LM, Bonow RH, Ravanpay A, Ellenbogen R, Huoy P, Thy T, Sothea S, Pak S, LoGerfo J, Lele AV (2019) A mixed-methods needs assessment of traumatic brain injury care in a low- and middle-income country setting: building neurocritical care capacity at two major hospitals in Cambodia. J Neurosurg 13:244–250
39. Belayneh Z, Zegeye A, Tadesse E, Asrat B, Ayano G, Mekuriaw B (2021) Level of anxiety symptoms and its associated factors among nurses working in emergency and intensive care unit at public hospitals in Addis Ababa Ethiopia. BMC Nurs 20:180
40. Carter C, Mukonka PS, Sitwala LJ, Howard-Hunt B, Notter J (2020) The development of critical care nursing education in Zambia. Br J Nurs 29:499–505
41. Chavula C, Pigoga JL, Kafwamfwa M, Wallis LA (2019) Cross-sectional evaluation of emergency care capacity at public hospitals in Zambia. Emerg Med J 36:620–624
42. Chiwaula CH, Jere DL (2022) Experiences of nurse managers and practitioners on implementation of an evidence-based practice intervention. Health SA Gesondheid 27:1597
43. Coyle RM, Harrison HL (2015) Emergency care capacity in Freetown, Sierra Leone: a service evaluation. BMC Emerg Med 15:2
44. Credland N (2014) Critical care nursing in Mburara, Uganda. Nurs Crit Care 19:213
45. Crit CA (2020) Establishing a critical care network in Asia to improve care for critically ill patients in low- and middle-income countries. Crit Care 24:608
46. Cummings MJ, Goldberg E, Mwaka S, Kabajaasi O, Vittinghoff E, Cattamanchi A, Katamba A, Kenya-Mugisha N, Jacob ST, Davis JL (2017) A complex intervention to improve implementation of World Health Organization guidelines for diagnosis of severe illness in low-income settings: a quasi-experimental study from Uganda. Implement Sci 12:126
47. Dart PJ, Kinnear J, Bould MD, Mwansa SL, Rakhda Z, Snell D (2017) An evaluation of inpatient morbidity and critical care provision in Zambia. Anaesthesia 72:172–180
48. Defaye FB, Desalegn D, Danis M, Hurst S, Berhane Y, Norheim OF, Miljeteig I (2015) A survey of Ethiopian physicians' experiences of bedside rationing: extensive resource scarcity, tough decisions and adverse consequences. BMC Health Serv Res 15:467
49. Firew T, Gebreyesus A, Woldeyohannes L, Ebrahim F, Patel S (2020) Human resources for emergency care systems in Ethiopia: challenges and triumphs. Afr J Emerg Med 10:S50-s55
50. Firth P, Ttendo S (2012) Intensive care in low-income countries: a critical need. N Engl J Med 367:1974–1976
51. Getahun YA, Bizuneh YB, Melesse DY, Chekol WB (2022) Assessment of practice and barriers of oxygen therapy in critically ill patients among nurses: a survey from University of Gondar Comprehensive Specialized Hospital Northwest, Ethiopia, 2021. Ann Med Surg (Lond) 76:103481

52. Gundo R, Mearns G, Dickinson A, Chirwa E (2019) Contextual issues that influence preparedness of nurses for critical care nursing practice in Malawi. Malawi Med J 31:138–143
53. Gundo R, Gundo B, Chirwa E, Dickinson A, Mearns GJ (2021) Effect of an educational programme on critical care nurses' competence at two tertiary hospitals in Malawi. Malawi Med J 33:236–241
54. Hadera T, Worku T, Tuli W (2022) Nurses' knowledge, practice, and associated factors with enteral nutrition in adult intensive care units of public hospitals. Ethiop J Health Sci 32:423–432
55. Hagos AA, Firew T, Gebreyesus A, Sambo BH, Reynolds TA (2019) Ethiopia's quest to champion emergency care systems. Bull World Health Organ 97:582
56. Holmaas G, Abate A, Woldetsadik A, Hevrøy O (2022) Establishing a sustainable training programme in anaesthesia in Ethiopia. Acta Anaesthesiol Scand 66:1016–1023
57. Hsia RY, Mbembati NA, Macfarlane S, Kruk ME (2012) Access to emergency and surgical care in sub-Saharan Africa: the infrastructure gap. Health Policy Plan 27:234–244
58. Jacob ST, Banura P, Baeten JM, Moore CC, Meya D, Nakiyingi L, Burke R, Horton CL, Iga B, Wald A, Reynolds SJ, Mayanja-Kizza H, Scheld WM (2012) The impact of early monitored management on survival in hospitalized adult Ugandan patients with severe sepsis: a prospective intervention study*. Crit Care Med 40:2050–2058
59. Janowicz A, Kasole T, Measures E, Langley M, Goma FM, Ismailova F, Kinnear JA, Bould MD (2017) Development of education and research in anesthesia and intensive care medicine at the university teaching hospital in Lusaka, Zambia: a descriptive observational study. Anesth Analg 125:287–293
60. Jochberger S, Ismailova F, Banda D, Mayr VD, Luckner G, Lederer W, Wenzel V, Wilson IH, Dünser MW (2010) A survey of the status of education and research in anaesthesia and intensive care medicine at the University Teaching Hospital in Lusaka, Zambia. Arch Iran Med 13:5–12
61. Jooste R, Roberts F, Mndolo S, Mabedi D, Chikumbanje S, Whitaker DK, O'Sullivan EP (2019) Global Capnography Project (GCAP): implementation of capnography in Malawi: an international anaesthesia quality improvement project. Anaesthesia 74:158–166
62. Kapiriri L, Arnesen T, Norheim OF (2004) Is cost-effectiveness analysis preferred to severity of disease as the main guiding principle in priority setting in resource poor settings? The case of Uganda. Cost Eff Resour Alloc 2:1
63. Kayambankadzanja RK, Likaka A, Mndolo SK, Chatsika GM, Umar E, Baker T (2020) Emergency and critical care services in Malawi: findings from a nationwide survey of health facilities. Malawi Med J 32:19–23
64. Kayambankadzanja RK, Schell CO, Mbingwani I, Mndolo SK, Castegren M, Baker T (2021) Unmet need of essential treatments for critical illness in Malawi. PLoS ONE 16:e0256361
65. Khudadad U, Aftab W, Ali A, Khan NU, Razzak J, Siddiqi S (2020) Perception of the healthcare professionals towards the current trauma and emergency care system in Kabul, Afghanistan: a mixed method study. BMC Health Serv Res 20:991
66. Kizza IB, Muliira JK (2015) Nurses' pain assessment practices with critically ill adult patients. Int Nurs Rev 62:573–582
67. Lalani HS, Waweru-Siika W, Kussin PS (2019) Reply: critical care in sub-saharan africa: is it ready for prime time? Ann Am Thorac Soc 16:157–158
68. Laytin AD, Sultan M, Debebe F, Walelign Y, Fisseha G, Gebreyesus A (2021) Critical care capacity in Addis Ababa, Ethiopia: a citywide survey of public hospitals. J Crit Care 63:1–7
69. Lecky FE, Reynolds T, Otesile O, Hollis S, Turner J, Fuller G, Sammy I, Williams-Johnson J, Geduld H, Tenner AG, French S, Govia I, Balen J, Goodacre S, Marahatta SB, DeVries S, Sawe HR, El-Shinawi M, Mfinanga J, Rubiano AM, Chebbi H, Do Shin S, Ferrer JME, Haddadi M, Firew T, Taubert K, Lee A, Convocar P, Jamaluddin S, Kotecha S, Yaqeen EA, Wells K, Wallis L (2020) Harnessing inter-disciplinary collaboration to improve emergency care in low- and middle-income countries (LMICs): results of research prioritisation setting exercise. BMC Emerg Med 20:68
70. Leligdowicz A, Bhagwanjee S, Diaz JV, Xiong W, Marshall JC, Fowler RA, Adhikari NK (2017) Development of an intensive care unit resource assessment survey for the care of critically ill patients in resource-limited settings. J Crit Care 38:172–176
71. Liyew B, Dejen Tilahun A, Kassew T (2020) Knowledge, attitude, and associated factors towards physical assessment among nurses working in intensive care units: a multicenter cross-sectional study. Crit Care Res Pract 2020:9145105
72. Liyew B, Tilahun AD, Kassew T (2021) Practices and barriers towards physical assessment among nurses working in intensive care units: multicenter cross-sectional study. Biomed Res Int 2021:5524676
73. MacLeod JB, Okech M, Labib M, Aphivantrakul P, Lupasha E, Nthele M (2011) Evaluation of trauma and critical care training courses on the knowledge and confidence of participants in Kenya and Zambia. World J Surg 35:9–16
74. Manda-Taylor L, Mndolo S, Baker T (2017) Critical care in Malawi: the ethics of beneficence and justice. Malawi Med J 29:268–271
75. Mersha AT, Gebre Egzi AHK, Tawuye HY, Endalew NS (2020) Factors associated with knowledge and attitude towards adult cardiopulmonary resuscitation among healthcare professionals at the University of Gondar Comprehensive Specialized Hospital, Northwest Ethiopia: an institutional-based cross-sectional study. BMJ Open 10:e037416
76. Minda Z, Samuel H, Aweke S, Mekete G, Seid A, Eshetie D (2022) Magnitude and associated factors of unplanned extubation in intensive care unit: a multi-center prospective observational study. Ann Med Surg (Lond) 79:103936
77. Mpasa F, van Rooyen DRM, Venter D, Jordan P, Ten Ham-Baloyi W (2020) Improving nurses' knowledge of managing endotracheal tube cuff pressure in intensive care units: a quasi-experimental study. Health SA 25:1479
78. Mula C (2014) Nurses' Competency and Challenges in Enteral feeding in the Intensive Care Unit (ICU) and High Dependency Units (HDU) of a referral hospital, Malawi. Malawi Med J 26:55–59
79. Nsutebu EF, Kellett J (2018) The Kampala declaration on sepsis: the recognition and treatment of severe illness starts at the bedside by recording vital signs. Eur J Intern Med 48:e9–e10
80. Ortiz-Barrios M, Alfaro-Saiz JJ (2020) An integrated approach for designing in-time and economically sustainable emergency care networks: a case study in the public sector. PLoS ONE 15:e0234984
81. Schultz MJ, Dünser MW, Dondorp AM, Adhikari NKJ, Iyer S, Kwizera A, Lubell Y, Papali A, Pisani L, Riviello ED, Angus DC, Azevedo LC, Baker T, Diaz JV, Festic E, Haniffa R, Jawa R, Jacob ST, Kissoon N, Lodha R, Martin-Loeches I, Lundeg G, Misango D, Mer M, Mohanty S, Murthy S, Musa N, Nakibuuka J, Neto AS, Mai NTH, Thien BN, Pattnaik R, Phua J, Preller J, Povoa P, Ranjit S, Talmor D, Thevanayagam J, Thwaites CL (2019) Current challenges in the management of sepsis in icus in resource-poor settings and suggestions for the future. In: Dondorp AM, Dünser MW, Schultz MJ (eds) Sepsis management in resource-limited settings. Springer, Cham, pp 1–24
82. Sherman CB, Carter EJ, Braendli O, Getaneh A, Schluger NW (2016) The east African training initiative. A model training program in pulmonary and critical care medicine for low-income countries. Ann Am Thorac Soc 13:451–455
83. Sonenthal PD, Kachimanga C, Komba D, Bangura M, Ludmer N, Lado M, Patino M, Gerrard RB, Vandy MJ, Marsh RH, Mukherjee J, Rouhani SA (2022) Applying the WHO-ICRC BEC course to train emergency and inpatient healthcare workers in Sierra Leone early in the COVID-19 outbreak. BMC Health Serv Res 22:197
84. Sonenthal PD, Nyirenda M, Kasomekera N, Marsh RH, Wroe EB, Scott KW, Bukhman A, Connolly E, Minyaliwa T, Katete M, Banda-Katha G, Mukherjee JS, Rouhani SA (2022) The Malawi emergency and critical care survey: a cross-sectional national facility assessment. EClinicalMedicine 44:101245
85. Sulieman H, El-Mahdi W, Awadelkareem M, Nazer L (2018) Characteristics of critically-ill patients at two tertiary care hospitals in Sudan. Sultan Qaboos Univ Med J 18:e190–e195
86. Sultan M, Mengistu G, Debebe F, Azazh A, Trehan I (2018) The burden on emergency centres to provide care for critically ill patients in Addis Ababa, Ethiopia. Afr J Emerg Med 8:150–154
87. Tefera BZ, Zeleke H, Abate A, Abebe H, Mekonnen Z, Sewale Y (2021) Magnitude and associated factors of low back pain among nurses working at intensive care unit of public hospitals in Amhara region, Ethiopia. PLoS ONE 16:e0260361
88. Tunpattu S, Newey V, Sigera C, De Silva P, Goonarathna A, Aluthge I, Thambavita P, Perera R, Meegahawatte A, Isaam I, Dondorp AM,

Haniffa R (2018) A short, structured skills training course for critical care physiotherapists in a lower-middle income country. Physiother Theory Pract 34:714–722
89. Ulisubisya M, Jörnvall H, Irestedt L, Baker T (2016) Establishing an anaesthesia and intensive care partnership and aiming for national impact in Tanzania. Global Health 12:7
90. Morton B, Vercueil A, Masekela R, Heinz E, Reimer L, Saleh S, Kalinga C, Seekles M, Biccard B, Chakaya J, Abimbola S, Obasi A, Oriyo N (2022) Consensus statement on measures to promote equitable authorship in the publication of research from international partnerships. Anaesthesia 77:264–276
91. Mounier-Jack S, Griffiths UK, Closser S, Burchett H, Marchal B (2014) Measuring the health systems impact of disease control programmes: a critical reflection on the WHO building blocks framework. BMC Public Health 14:278
92. Kayambankadzanja RK, Schell CO, Gerdin WM, Tamras T, Mollazadegan H, Holmberg M, Alvesson HM, Baker T (2022) Towards definitions of critical illness and critical care using concept analysis. BMJ Open 12:e060972
93. ICS (2021) Levels of care. https://ics.ac.uk/resource/levels-of-care.html. Accessec 27 Dec 2022
94. Valentin A, Ferdinande P (2011) Recommendations on basic requirements for intensive care units: structural and organizational aspects. Intensive Care Med 37:1575–1587
95. Zealand COICMOAAN (2011) Minimum standards for intensive care units. https://cicm.org.au/CICM_Media/CICMSite/CICM-Website/Resources/Professional%20Documents/IC-1-Minimum-Standards-for-Intensive-Care-Units_1.pdf. Accessed 16 Jan 2023
96. Marshall JC, Bosco L, Adhikari NK, Connolly B, Diaz JV, Dorman T, Fowler RA, Meyfroidt G, Nakagawa S, Pelosi P, Vincent JL, Vollman K, Zimmerman J (2017) What is an intensive care unit? A report of the task force of the World Federation of Societies of Intensive and Critical Care Medicine. J Crit Care 37:270–276
97. Kazibwe J, Shah HA, Kuwawenaruwa A, Schell CO, Khalid K, Tran PB, Ghosh S, Baker T, Guinness L (2022) Resource use, availability and cost in the provision of critical care in Tanzania: a systematic review. BMJ Open 12:e060422
98. Lalani HS, Waweru-Siika W, Mwogi T, Kituyi P, Egger JR, Park LP, Kussin PS (2018) Intensive care outcomes and mortality prediction at a National Referral Hospital in western Kenya. Ann Am Thorac Soc 15:1336–1343
99. Prin M, Itaye T, Clark S, Fernando RJ, Namboya F, Pollach G, Mkandawire N, Sobol J (2016) Critical care in a tertiary hospital in Malawi. World J Surg 40:2635–2642
100. Engdahl Mtango S, Lugazia E, Baker U, Johansson Y, Baker T (2019) Referral and admission to intensive care: a qualitative study of doctors' practices in a Tanzanian university hospital. PLoS ONE 14:e0224355
101. Biccard BM, Gopalan PD, Miller M, Michell WL, Thomson D, Ademuyiwa A, Aniteye E, Calligaro G, Chaibou MS, Dhufera HT, Elfagieh M, Elfiky M, Elhadi M, Fawzy M, Fredericks D, Gebre M, Bayih AG, Hardy A, Joubert I, Kifle F, Kluyts H-L, Macleod K, Mekonnen Z, Mer M, Morais A, Msosa V, Mulwafu W, Ndonga A, Ngumi Z, Omigbodun A, Owoo C, Paruk F, Piercy JL, Seman Y, Taylor EH, van Straaten D, Elfiky M, Fawzy M, Awad A, Hussein H, Shaban M, Elbadawy M, Elmehrath AO, Cordie A, Elganainy M, El-Shazly M, Essam M, Abdelwahab OA, Ali A, Hussein AM, kamel EZ, Monib FA, Ahmed I, Saad MM, Al-Quossi MA, Rafaat N, Galal I, labib B, Omran DO, Fawzy M, Elfiky M, Azzam A, Azab M, Ghozy S, Tawheed A, Gamal M, El Kassas M, Azzam A, Ahmed N, NasrEldin Y, Abdelsalam A, Abdewahab O, Elganainy M, Elmandouh O, Dhufera HT, Gebre M, Bayih AG, Kifle F, Mekonnen Z, Seman Y, Addisie A, Eshete A, Kifle F, Desita K, Araya H, Agidew Y, Andabo AD, Tesfaye E, Yesuf EA, Hailemariam G, Sime H, Keneni DF, Mohammed MS, Gebremedhin Y, Taye Y, Mebrate TA, Gemechu TB, Bedane TT, Abera ET, Teshome A, Aniteye E, Owoo C, Doku A, Owoo C, Afriyie-Mensah JS, Lawson A, Owoo C, Sottie DA, Addae E, Ofosu-Appiah E, Obeng W, Ndonga A, Ngumi Z, Ndonga A, Mugera A, Bitta C, Elfagieh M, Elhadi M, Huwaysh MA, Yahya MMA, Mohammed AAK, Majeed AAM, Mohammed AEM, Majeed E, Abusalama AA, Altayr E, Abubaker T, Alkaseek AM, Abdulhafith B, Alziyituni Z, Gamra MF, Anaiba MM, Khel S, Abdelkabir M, Abdeewi S, Adam S, Alhadi A, Alsoufi A, Binnawara M, Msherghi A, Bouhuwaish AEM, Taher ASA, Msosa V, Mulwafu W, Masoo F, Chikumbanje SS, Chisala P, Mabedi D, Morais A, Carlos A, Morais A, Lorenzoni C, Mambo J, Isabel Chissaque I, Mouzinho Saide M, Chaibou MS, Mamane M, Amadou F, Adesoji Ademuyiwa AA, Akinyinka Omigbodun AO, Adeyeye A, Akinmade A, Momohsani Y, Bamigboye J, Orshio D, Isamade ES, Embu H, Nuhu S, Ojiakor S, Nuhu A, Kwayabura S, Fowotade A, Sanusi A, Osinaike B, Idowu O, Adekanmbi O, Amali AO, Ibrahim S, Adamu AA, Kida I, Otokwala J, Essam M, Alagbe-Briggs O, Ojum S, Paruk F, Scribante J, Kalla IS, Mdladla A, Mabotja T, Naidoo R, Matos-Puig R, Ramkillawan A, Smith M, Arnold-Day C, Thomson D, Calligaro G, Joubert I, Jagga J, Piercy J, Michell L, Devenish L, Miller M, Fernandes N, Gopalan PD, Pershad S, Grabowski N, Rammego M, Zwane S, Dhlamini ME, Neuhoff M, Fodo T, Usenbo A, Mrara B, Kabambi F, Cloete E, De Caires L, Dickerson R, Louw C, Theron A, Herselman R, Badenhorst J, Moletsane G, Loots H, Vorster FC, Paruk F, Chausse J, Neuhoff M, Sebastian M, Grabowski N, Rheeder P, van Hougenhouck-Tulleken W, Snyman C, Adeleke D, Esterhuizen J, de Man L, Mosola M, van der Linde P, Swart R, Maasdorp S, Martins T, Govender V (2021) Patient care and clinical outcomes for patients with COVID-19 infection admitted to African high-care or intensive care units (ACCCOS): a multicentre, prospective, observational cohort study. Lancet 397: 1885–1894
102. Rudakemwa A, Cassidy AL, Twagirumugabe T (2021) High mortality rate of obstetric critically ill women in Rwanda and its predictability. BMC Pregnancy Childbirth 21:401
103. Atinga RA, Kuganab-Lem RB, Aziato L, Srofenyoh E (2015) Strengthening quality of acute care through feedback from patients in Ghana. Afr J Emerg Med 5:24–30
104. WHO (2019) Emergency Care. https://www.who.int/health-topics/emergency-care#tab=tab_1. Accessed 27 March 2023
105. Mitchell R, McKup JJ, Bue O, Nou G, Taumomoa J, Banks C, O'Reilly G, Kandelyo S, Bornstein S, Cole T, Ham T, Miller JP, Reynolds T, Körver S, Cameron P (2020) Implementation of a novel three-tier triage tool in Papua New Guinea: a model for resource-limited emergency departments. Lancet Reg Health West Pac 5:100051
106. Baelani I, Jochberger S, Laimer T, Otieno D, Kabutu J, Wilson I, Baker T, Dunser MW (2011) Availability of critical care resources to treat patients with severe sepsis or septic shock in Africa: a self-reported, continent-wide survey of anaesthesia providers. Crit Care 15:R10
107. Papali A, McCurdy MT, Calvello EJ (2015) A "three delays" model for severe sepsis in resource-limited countries. J Crit Care 30(861):e814–e869
108. Murthy S, Adhikari NK (2013) Global health care of the critically ill in low-resource settings. Ann Am Thorac Soc 10:509–513
109. Morton B, Stolbrink M, Kagima W, Rylance J, Mortimer K (2018) The early recognition and management of sepsis in sub-saharan african adults: a systematic review and meta-analysis. Int J Environ Res Public Health 15:2017
110. Kilonzo KG, Akrabi HF, Yeates KE (2020) Cost-effectiveness of acute peritoneal dialysis: Considerations from Africa. Clin Nephrol 93:72–75
111. WHO (2022) Health workforce. https://www.who.int/health-topics/health-workforce#tab=tab_1. Accessed 21 Dec 2022
112. Bank W (2017) World development indicators: health systems. http://wdi.worldbank.org/table/2.12. Accessed 20 Apr 2023
113. WHO (2022) Global Health Workforce statistics database. https://www.who.int/data/gho/data/themes/topics/health-workforce. Accessed 21 Dec 2022
114. Siaw-Frimpong M, Touray S, Sefa N (2021) Capacity of intensive care units in Ghana. J Crit Care 61:76–81
115. Arabi YM, Taher S, Berenholtz SM, Alamry A, Hijazi R, Alatassi A, Marini AM (2013) Building capacity for quality and safety in critical care: a roundtable discussion from the second international patient safety conference in April 9–11, 2013, Riyadh Saudi Arabia. Ann Thorac Med 8:183–185
116. Schluger NW, Sherman CB, Binegdie A, Gebremariam T, Kebede D, Worku A, Carter EJ, Brändli O (2018) Creating a specialist physician workforce in low-resource settings: reflections and lessons learnt from the East African Training Initiative. BMJ Glob Health 3:e001041
117. Ehteshami A, Sadoughi F, Ahmadi M, Kashefi P (2013) Intensive care information system impacts. Acta Inform Medica 21:185
118. Koumamba AP, Bisvigou UJ, Ngoungou EB, Diallo G (2021) Health information systems in developing countries: case of African countries. BMC Med Inform Decis Mak. https://doi.org/10.1186/s12911-021-01597-5

119. Jawad I, Rashan S, Sigera C, Salluh J, Dondorp AM, Haniffa R, Beane A (2021) A scoping review of registry captured indicators for evaluating quality of critical care in ICU. J Intensive Care. https://doi.org/10.1186/s40560-021-00556-6
120. SanJoaquin MA, Allain TJ, Molyneux ME, Benjamin L, Everett DB, Gadabu O, Rothe C, Nguipdop P, Chilombe M, Kazembe L, Sakala S, Gonani A, Heyderman RS (2013) Surveillance Programme of IN-patients and Epidemiology (SPINE): implementation of an electronic data collection tool within a large hospital in Malawi. PLoS Med 10:e1001400
121. Tossaint-Schoenmakers R, Versluis A, Chavannes N, Talboom-Kamp E, Kasteleyn M (2021) The challenge of integrating ehealth into health care: systematic literature review of the Donabedian model of structure, process, and outcome. J Med Internet Res 23:e27180
122. Pisani L, Rashan T, Shamal M, Ghose A, Kumar TVB, Tripathy S, Aryal D, Hashmi M, Nor B, Lam-Minh Y, Dondorp AM, Haniffa R, Beane A (2021) Performance evaluation of a multinational data platform for critical care in Asia. Welcome Open Res 6:251
123. Pisani L, Waweru-Siika W, Sendagire C, Beane A, Haniffa R (2021) Critically ill COVID-19 patients in Africa: it is time for quality registry data. Lancet 398:485–486
124. Aryal D, Beane A, Dondorp AM, Green C, Haniffa R, Hashmi M, Jayakumar D, Marshall JC, McArthur CJ, Murthy S, Webb SA, Acharya SP, Ishani PGP, Jawad I, Khanal S, Koirala K, Luitel S, Pabasara U, Paneru HR, Kumar A, Patel SS, Ramakrishnan N, Salahuddin N, Shaikh M, Tolppa T, Udayanga I, Umrani Z (2021) Operationalisation of the randomized embedded multifactorial adaptive platform for COVID-19 trials in a low and lower-middle income critical care learning health system. Welcome Open Res 6:14
125. Purgato M, Barbui C (2012) What is the WHO essential medicines list? Epidemiol Psychiatr Sci 21:343–345
126. WHO (2022) The selection and use of essential medicines (2021): TRS 1035. https://www.who.int/publications/i/item/9789240041134. Accessed 16 Jan 2023
127. PAHO (2020) Essential medicines list for management of patients admitted to intensive care units with suspected or confirmed COVID-19 diagnosis. https://www.paho.org/en/documents/essential-medicines-list-management-patients-admitted-intensive-care-units-suspected-or. Accessed 16 Jan 2023
128. Broccoli MC, Pigoga JL, Nyirenda M, Wallis LA, Calvello Hynes EJ (2018) Essential medicines for emergency care in Africa. Afr J Emerg Med 8:110–117
129. PATH (2017) New WHO designation for oxygen could save thousands of lives globally. https://www.path.org/media-center/new-who-designation-for-oxygen-could-save-thousands-of-lives-globally/. Accessed 16 Jan 2023
130. Yadav P (2015) Health product supply chains in developing countries: diagnosis of the root causes of underperformance and an Agenda for reform. Health Syst Reform 1:142–154
131. Howie SR, Ebruke BE, Gil M, Bradley B, Nyassi E, Edmonds T, Boladuadua S, Rasili S, Rafai E, Mackenzie G, Cheng YL, Peel D, Vives-Tomas J, Zaman SM (2020) The development and implementation of an oxygen treatment solution for health facilities in low and middle-income countries. J Glob Health 10:020425
132. Knaul FM, Bhadelia A, Rodriguez NM, Arreola-Ornelas H, Zimmermann C (2018) The Lancet Commission on Palliative Care and Pain Relief—findings, recommendations, and future directions. Lancet Glob Health 6:S5–S6
133. WHO (2020) WHO publishes pricing policy guideline to improve affordable access to medicines. https://www.who.int/news/item/28-09-2020-who-publishes-pricing-policy-guideline-to-improve-affordable-access-to-medicines. Accessed 16 Jan 2023
134. WHO (2022) ACT-accelerator outcomes report, 2020–22. https://www.who.int/publications/m/item/act-accelerator-outcomes-report--2020-22. Accessed 16 Jan 2023
135. Vukoja M, Riviello E, Gavrilovic S, Adhikari NK, Kashyap R, Bhagwanjee S, Gajic O, Kilickaya O (2014) A survey on critical care resources and practices in low- and middle-income countries. Glob Heart 9:337–342
136. Boakye G, Gyedu A, Stewart M, Donkor P, Mock C, Stewart B (2021) Assessment of local supply chains and stock management practices for trauma care resources in Ghana: a comparative small sample cross-sectional study. BMC Health Serv Res 21:66
137. Pari V (2022) Development of a quality indicator set to measure and improve quality of ICU care in low- and middle-income countries. Intensive Care Med 48:1551–1562
138. WHO (2022) Universal health coverage (UHC). https://www.who.int/news-room/fact-sheets/detail/universal-health-coverage-(uhc). Accessed 20 Apr 2023
139. Hanson K, Brikci N, Erlangga D, Alebachew A, De Allegri M, Balabanova D, Blecher M, Cashin C, Esperato A, Hipgrave D, Kalisa I, Kurowski C, Meng Q, Morgan D, Mtei G, Nolte E, Onoka C, Powell-Jackson T, Roland M, Sadanandan R, Stenberg K, Vega Morales J, Wang H, Wurie H (2022) TheLancet Global Health Commission on financing primary health care: putting people at the centre. Lancet Glob Health 10:e715–e772
140. Initiative IDS (2022). https://idsihealth.org/who-we-are/about-us/. Accessed 21 Jan 2022
141. Barasa E, Rogo K, Mwaura N, Chuma J (2018) Kenya National Hospital insurance fund reforms: implications and lessons for universal health coverage. Health Syst Reform 4:346–361
142. Higgins AM, Pettila V, Bellomo R, Harris AH, Nichol AD, Morrison SS (2010) Expensive care - a rationale for economic evaluations in intensive care. Crit Care Resusc 12:62–66
143. The L (2020) Global health: time for radical change? Lancet 396:1129
144. Kyeremanteng K, Wan C, D'Egidio G, Neilipovitz D (2016) Approach to economic analysis in critical care. J Crit Care 36:92–96
145. Reynolds TA, Sawe H, Rubiano AM, Shin SD, Wallis L, Mock CN (2023) Strengthening health systems to provide emergency care. In: Jamison DT, Gelband H, Horton S, Jha P, Laxminarayan R, Mock CN, Nugent R (eds) Disease control priorities: improving health and reducing poverty. The International Bank for Reconstruction and Development / The World Bank, Washington
146. Marotta C, Di Gennaro F, Pisani L, Pisani V, Senesie J, Bah S, Koroma MM, Caracciolo C, Putoto G, Amatucci F, Borgonovi E (2020) Cost-utility of intermediate obstetric critical care in a resource-limited setting: a value-based analysis. Ann Glob Health 86:82
147. Kayambankadzanja RK, Schell CO, Namboya F, Phiri T, Banda-Katha G, Mndolo SK, Bauleni A, Castegren M, Baker T (2020) The prevalence and outcomes of sepsis in adult patients in two hospitals in Malawi. Am J Trop Med Hyg 102:896–901
148. Guinness L, Kairu A, Kuwawenaruwa A, Khalid K, Awadh K, Were V, Barasa E, Shah H, Baker P, Schell CO, Baker T (2023) Essential emergency and critical care as a health system response to critical illness and the COVID19 pandemic: what does it cost? Cost Eff Resour Alloc 21:15
149. WHO (2019) Emergency care systems for universal health coverage: ensuring timely care for the acutely ill and injured. Resolution WHA72.16. Seventy second world health assembly. World Health Organization, Geneva
150. Bank TW (2022) World bank country and lending groups. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups. Accessed 28 Jan 2023
151. NIHR (2021) Funding applied global health research and training… to meet the needs of the poorest people in low and middle income countries. https://www.nihr.ac.uk/documents/best-research-for-best-health-the-next-chapter/27778#funding-applied-global-health-research-and-training-to-meet-the-needs-of-the-poorest-people-in-low-and-middle-income-countries. Accessed 01 June 2023
152. Collaboration for Research, Training and Implementation in Critical Care in Asia and Africa (CCAA).