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Global perioperative care in Africa

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Global perioperative care in Africa

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Editorial: Global perioperative care in Africa

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Editorial on the Research Topic
Global perioperative care in Africa

Perioperative care and critical care medicine are fundamental to providing universal health coverage, yet they remain among the least equitably distributed services worldwide. Today, an estimated 5 billion people lack access to safe, affordable surgical and anesthesia care, underscoring the urgency of system-wide solutions (1). The *Frontiers in Medicine* Research Topic *Global Perioperative Care in Africa* brings together a multidisciplinary body of evidence that underscores both the complexity and the promise of advancing surgical, anesthesia, and critical care capacity across low- and middle-income countries. These studies reflect a shared goal: using clinical innovation and research to strengthen health systems and create equity in Africa.

Innovation grounded in context

The Research Topic opens with work that exemplifies the adaptive ingenuity of clinicians and engineers who must respond to resource constraints. In "*A comparative analysis of intravenous infusion methods for low-resource environments*," Tomobi et al. evaluate pragmatic infusion strategies suitable for hospitals where electricity and consumables are limited. Their findings remind us that technology design must begin with end-user realities. Similarly, in "*Bridging the mismatch: observing the introduction of new anesthesia technology for a low-resource environment*," Sampson et al. demonstrate that sustainable adoption of biomedical innovation requires participatory learning, co-creation, and local ownership. Both studies highlight that scientific rigor and contextual empathy are not opposing values but complementary foundations of sustainable innovation.

Workforce and systems as catalysts for change

Strengthening human resources and institutional processes emerges as a unifying theme across the Research Topic. In "*Strengthening nursing knowledge and skills in perioperative cleft care: a focused training approach in Nigeria's surgical healthcare plan*," Lawal et al. present a model for targeted, context-specific nurse education that extends beyond skill acquisition to empowerment and retention. "*The landscape of perioperative nursing education in Africa: a scoping review*" Wong et al. broadens this conversation, mapping curricular gaps and policy opportunities to professionalize perioperative nursing across the continent.

At the systems level, "*Development, implementation, and evaluation of a rapid response system at a Nigerian teaching hospital, a novel idea in sub-Saharan Africa*," Ariyo et al. introduces an evidence-based framework for in-hospital emergency response—a novel concept in many sub-Saharan contexts. This intervention demonstrates how structured communication, early warning tools, and multidisciplinary teamwork can reduce preventable deaths and foster a culture of safety.

Local evidence for global relevance

Building a global science of perioperative care requires evidence generated within the regions where needs are greatest. In "*Mortality and its associated factors among mechanically ventilated adult patients in the intensive care units of referral hospitals in Northwest Amhara, Ethiopia*" Tadesse et al., outcome data collected from local intensive care units illuminate risk factors that global datasets often overlook. "*Healthcare providers' knowledge, attitude, and practice toward cervical cancer screening in sub-Saharan Africa: systematic review and meta-analysis*" Delie et al. similarly emphasizes the translational value of regional research for broader health-system planning. Finally, "*Ultrasound assessment of diaphragmatic dysfunction in non-critically ill patients: relevant indicators and update*," Yao et al. illustrates how advances in diagnostic science can inform perioperative and critical care pathways across settings.

Collectively, these articles challenge the historic one-way flow of scientific knowledge from high- to low-income contexts. By prioritizing African data, they expand the global evidence base, making it both more representative and more actionable.

Financing, partnerships, and the path to equity

Scientific progress alone cannot sustain system transformation without corresponding investment and policy alignment. Financing mechanisms for perioperative and critical care remain fragmented, often dependent on short-term donor cycles rather than long-term infrastructure and workforce development. To realize the vision articulated in this Research Topic, health-system strengthening must be recognized as a global public good—worthy of stable financing akin to vaccination or disease surveillance programs. Without sustained investment, even the most promising innovations cannot close the surgical access gap highlighted by the Lancet Commissions's findings.

Advocacy networks such as the G4 Alliance, the Johns Hopkins Global Alliance of Perioperative Professionals, and other regional and diaspora-led coalitions have a crucial role in aligning governments, academia, and philanthropy around this agenda. Their combined advocacy underscores that equitable surgical and critical care is not a luxury of wealthy nations but a prerequisite for resilient health systems everywhere.

Conclusion: toward a science of systems

The articles gathered under *Global Perioperative Care in Africa* collectively redefine what constitutes global health research. They move the field from isolated interventions toward a science of systems—where engineering, clinical medicine, public health, and economics converge to strengthen institutional capacity. This Research Topic invites continued collaboration among clinicians, researchers, engineers, and policymakers to expand the frontiers of equitable care. By embedding innovation within local systems, nurturing regional research capacity, and mobilizing global partnerships, the contributors to this Research Topic chart a path toward sustainable, evidence-based perioperative and critical care for all.

Global health equity will be achieved not by technology alone, but by the deliberate alignment of science, solidarity, and sustained investment.

Author contributions

PA: Writing – original draft, Writing – review & editing. JS: Writing – original draft, Writing – review & editing. SC: Writing – original draft, Writing – review & editing. IE: Writing – original draft, Writing – review & editing. EJ: Writing – original draft, Writing – review & editing.

Conflict of interest

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References

1. Meara JG, Greenberg SL. The Lancet Commission on Global Surgery Global surgery 2030: evidence and solutions for achieving health, welfare and economic development. *Surgery*. (2015) 157:834–5. doi: 10.1016/j.surg.2015.02.00

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A comparative analysis of intravenous infusion methods for low-resource environments

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Introduction: Intravenous (IV) therapy is a crucial aspect of care for the critically ill patient. Barriers to IV infusion pumps in low-resource settings include high costs, lack of access to electricity, and insufficient technical support. Inaccuracy of traditional drop-counting practices places patients at risk. By conducting a comparative assessment of IV infusion methods, we analyzed the efficacy of different devices and identified one that most effectively bridges the gap between accuracy, cost, and electricity reliance in low-resource environments.

Methods: In this prospective mixed methods study, nurses, residents, and medical students used drop counting, a manual flow regulator, an infusion pump, a DripAssist, and a DripAssist with manual flow regulator to collect normal saline at goal rates of 240, 120, and 60 mL/h. Participants' station setup time was recorded, and the amount of fluid collected in 10 min was recorded (in milliliters). Participants then filled out a post-trial survey to rate each method (on a scale of 1 to 5) in terms of understandability, time consumption, and operability. Cost-effectiveness for use in low-resource settings was also evaluated.

Results: The manual flow regulator had the fastest setup time, was the most cost effective, and was rated as the least time consuming to use and the easiest to understand and operate. In contrast, the combination of the DripAssist and manual flow regulator was the most time consuming to use and the hardest to understand and operate.

Conclusion: The manual flow regulator alone was the least time consuming and easiest to operate. The DripAssist/Manual flow regulator combination increases accuracy, but this combination was the most difficult to operate. In addition, the manual flow regulator was the most cost-effective. Healthcare providers can adapt these devices to their practice environments and improve the safety of rate-sensitive IV medications without significant strain on electricity, time, or personnel resources.

KEYWORDS

cost-effectiveness analysis, global health disparities, critically ill, low-resource setting, intravenous infusion therapy, sedation

1 Introduction

Intravenous (IV) therapy is used to achieve homeostatic balance and is crucial to the care of critically ill patients. Intravenous fluids are required to maintain or increase cardiac output vital for tissue perfusion and for the sedation necessary to promote healing during admission to an intensive care unit (ICU) (1). Yet, excessive administration or under-delivery of fluids or medications can result in complications that contribute to morbidity and mortality (2). Furthermore, accuracy, cost, and the perspectives of healthcare workers with respect to the range of IV therapies available are still minimally explored in the low-resource setting.

In critically ill patients with hemodynamic instability, such as with distributive shock, appropriate fluid balance is crucial. Aggressive fluid administration can result in volume overload and worsen the patient's condition (3–6). Similarly, sedation overdosage and underdosage can negatively affect health measures such as the depth of sedation for ventilator use or successful pain management to reduce hospital stay. Accurate infusion methods can improve recovery outcomes in the ICU and reduce hospital stay (7). Although different IV delivery methods may have different levels of accuracy, additional factors must be considered for low-resource environments.

Accuracy in delivering IV fluids and other medications is achieved by using infusion pumps and other volumetric devices. Many of these devices are expensive and require electricity. Most available infusion pumps range in price from $1,200 to $4,000 each (8) and may be prohibitively expensive in low-resource settings. To overcome these financial barriers, other devices may be considered.

Health providers in low-resource settings usually resort to drop-counting, which relies on raising the IV bag above a patient to increase the hydrostatic pressure to overcome the vein's peripheral pressure, and observing the flow rate by counting the number of drops per minute (9). Inaccuracy of traditional drop-counting practices places patients at risk for complications that may increase morbidity and mortality (9).

The manual flow regulator is a circular device that allows the healthcare provider to manually set the flow rate in milliliters per hour (10). This device is advantageous because it facilitates a consistent infusion rate, does not require electricity or batteries, and costs $4.00 U.S. dollars (USD). A disadvantage, however, is that the accuracy may not approach that of the IV infusion pump.

A portable device known as the DripAssist has been shown in 2 studies to be accurate and can be used in low-resource settings such as prehospital and military medicine (11, 12). The DripAssist was developed to administer IV fluid infusions in low-resource areas at a low cost with no electricity requirements (11, 12). Each DripAssist device is priced at $400 USD and requires one AA battery. Though the DripAssist provides a low-cost option for achieving accuracy in low-resource settings, it is very sensitive to any movement.

According to the current literature, accuracy, precision, and setup time are crucial considerations when comparing medical devices (5). In low-resource environments, such as India and Senegal, both overall costs and running considerations, such as electricity reliance, should be considered (13–17). The perceptions of healthcare workers are additionally important when it comes to the use of devices (18, 19). In this prospective mixed methods comparative study, we aimed to compare the different methods available for IV infusions that require close volume and rate control. To this end, we (1) compared the accuracy, precision, and setup time over 3 drip goals of 5 IV infusion methods, (2) evaluated healthcare worker perception of these options, and finally (3) conducted a cost-effectiveness analysis of the devices. The ultimate goal of this analysis is to identify a device that bridges the gap between accuracy, cost, and electricity reliance for IV infusion methods in low-resource settings.

2 Methods

This study was a mixed-methods prospective trial and a cost-effectiveness analysis to compare IV infusion devices in terms of their use in 2 countries, Senegal and India. It was conducted at the Johns Hopkins University School of Medicine and Howard Community College and was approved by the Institutional Review Boards at both institutions (IRB00254064 and HCC – 2021-08-25, respectively). This approval included special permission to conduct research with institutional employees and special permission from the nursing department leadership to recruit nurses. Participants were informed about the study through a detailed consent form, which was signed prior to participation.

2.1 Participant recruitment

The study included a set of local health nurse, resident, and medical student volunteers. Inclusion criteria for participants included age $\geq$ 18 years, training or practicing with a minimum of a registered nurse (RN) license for nurses, a medical degree for resident trainees in the workforce, or enrollment in a U.S. medical school for medical students. Sample size determination was based on sufficient numbers needed for usability studies (at least 30 for quantitative analysis) (20). No patients were involved in the study. For this study, recruitment was targeted at local nurses who could participate at either the Johns Hopkin Hospital site or the Howard Community College site (both in Maryland) because nurses are typically responsible for administering the proper IV infusion rate prescribed by the doctor. Medical students and residents were also recruited to the study because residents are also part of the workforce in low-resource settings and because we wanted to investigate whether medical students with no experience could easily learn the IV infusion setup.

Exclusion criteria included nurses with less than an RN level of education, and undergraduate (pre-health) students.

Electronic flyers were created to advertise the study and to recruit participants. Participants were scheduled in advance or recruited onsite on the day of participation. Prior to the experiment, participants had the option of watching a demonstration of each IV infusion method through a series of videos made by the researchers. They also had the option of observing a 5-min, live, in-person didactic and demonstration session of each IV infusion at the time of registration. Incentives for participation included a free designer Risen Regalia facemask, a chance to win an Amazon or Visa gift card in a raffle, or a hospital cafeteria gift card.

2.2 Study design

Healthcare nurses and trainee volunteers were asked to operate 5 different IV infusion methods (Figure 1). Each method was performed at one of 5 stations: manually counting drops (station 1), using an IV

FIGURE 1
Intravenous (IV) infusion methods. **(A)** Drop counting. This method is the most traditional way of delivering infusions in low-resource settings. Gravity is used as the driving force to administer the IV fluid through tubing with a drip chamber. **(B)** IV infusion pump. The Alaris IV infusion pump is a relatively expensive device that administers fluid in controlled amounts using a built-in software interface. **(C)** The DripAssist is a small, lightweight device that operates with one AA battery. The rate of fluid infused is automatically monitored by the device itself. The DripAssist device also uses an alarm technology that alerts the user of a significant change in drip rate. It provides a display of the rate as milliliters/h, drops/min, or total milliliters. **(D)** The manual flow regulator is a simple cylindrical device that is attached to the IV tubing and allows the user to set the flow to a constant rate. This device may make the infusion process easier, although the drip rate must be monitored occasionally.

manual flow regulator (station 2), using an Alaris IV infusion pump: BD Alaris™ Pump Module (station 3), using the DripAssist device: DripAssist Infusion Rate Monitor from Shiftlabs (station 4), and using the DripAssist device and the IV manual flow regulator together (station 5). Each station had 1 to 3 IV bags, an IV pole, an infusion set, timers, and 3 graduated cylinders. The IV bags contained saline solution, and all the parameters, including IV fluid bag, fluid type, and fluid viscosity, were kept the same to avoid confounding bias. Study team members were aware that 1 mL in different solutions could lead to different drop count measurements; thus, IV saline was the only IV fluid used in the study.

For accurate volume measurements, the fluid was collected in a 250 mL graduated cylinder clamped to a stand.

2.3 Data collection

Each data collector was trained on how to operate equipment at each station and how to demonstrate each station to study participants. We employed beta-testing with 10 participants to refine our recruitment, enrollment, equipment use, and data collection methods. These participants were not reflected in the participant demographics or data analysis. Outcomes included station setup time, drip rate accuracy, drip rate precision, and cost of using these devices in an acute care setting. Participants completed a questionnaire after the trial in which they were asked to rate the operability, understandability, and perceived time consumption of each method on a 5-point Likert scale. Participants also had the option to leave qualitative comments on the survey, which we separately analyzed for common themes.

The accuracy and precision of each device was measured by comparing drip rates. The participants were asked to set each device to a specific drip rate: 240, 120, and 60 mL/h. After 10 min, the researcher measured the total volume collected in the cylinder and calculated the drip rate with the following formula:

$$drip\ rate = \frac{volume\,(mL)}{time\,(\min)}$$

Study team members were aware that 1 mL in different solutions could indicate a different drop count; thus, IV saline was the only IV fluid used in the study.

The accuracy of the setup was independently determined by 2 researchers, who measured the volume of the fluid collected in the cylinder after 10 min. The difference between expected and calculated drip rate determined the accuracy level. The range of the standard deviation determined the precision, with a wider standard deviation demonstrating lower precision and a narrower standard deviation showing higher precision.

Setup time was recorded with a stopwatch and included the time to determine the given flow rate until the time that the participant was satisfied with the setup and informed the researcher. Setup time did not include the time to set up the bag (which was measured

TABLE 1 Costs associated with ICU care in Senegal and India.

Parameter	India	Senegal
Cost of ICU ventilator/day		
Public hospital	$7.50	NA[a]
Private hospital	$39.13	NA[a]
Cost of ICU stay/day		
Public hospital	$33.33 all inclusive	$55
Private hospital	$93.75 all inclusive	$330 to $400
Typical ICU bed count		
Public hospital	5 to 6	4 to 7
Private hospital	18	4 to 7
Nurse salary		
Public hospital	$740 to $2,100 per month (basic+DA)	$15 for 12 h
Private hospital	$5.30 per hour	NA
Physician salary		
Public hospital	Level 10 to 15: $740 to Rs 4,200 per month (basic +NPA + DA + TA)	$50 for 24 h
Private hospital	$14 per hour	$62 for 24 h
Cost of sedative/pain management medications		
Fentanyl	$0.45 per 100 mcg ampule	$14.00 per box
Ketamine	$0.52 per vial	$4.60 per box
Midazolam	$0.35 per vial	$4.67 per box
Morphine	$0.37 per ampule	$152.00 per box
PCM	$0.37 for 1 g infusion	NA
Diclofenac	$0.25 for 75 mg	NA
Ketolorac	$0.37 per injection	NA
Tramadol	$0.50 per injection	NA

ICU, intensive care unit; NA, not applicable. PCM, paracetamol. Rs, Rupees. NPA, Non-practicing allowance. DA, Dearness allowance. TA, Traveling allowance.
[a]There is no structure in Senegal that bills for ventilator use.

separately). We averaged and reported the bag setup times for those who set up the bag before setting up the infusion rate.

To accurately represent cost of care in an ICU setting, 2 investigators independently collected data about cost using public health resources in Senegal and India (21–25).

2.4 Cost-effectiveness modeling in Senegal and India

To determine the cost-effectiveness of the infusion methods in low-resources settings, we created a model of a hypothetical ICU in India and Senegal in which the methods would be deployed. The model assumed that a patient would enter the ICU and receive intravenous sedation therapy for 3 days. The cost measures were the costs of materials for each infusion method, time/hly wages for nurses and physicians, hospital stay, days on ventilator, and costs of sedatives (midazolam and fentanyl) at a rate of 10 mL/h (Table 1). We also made the assumption that the accuracy of the infusion method would be reflected in a patient's sedation score. A traditional Richmond-Agitation Sedation Scale (RASS) (26) ranges from +4 to −5. To make mathematical calculations and comparisons between the infusion methods possible, corresponding numerical equivalents (ranging from 1 to 10) were substituted for each RASS score (Table 2).

TABLE 2 Richmond-Agitation Sedation Scale (RASS).

RASS	Description	Numerical equivalent
+4	Combative	1
+3	Very agitated	2
+2	Agitated	3
+1	Restless	4
0	Alert & calm	5
-1	Drowsy	6
-2	Light sedation	7
−3	Moderate sedation	8
−4	Deep sedation	9
−5	Unarousable	10

Cost-effectiveness of the infusion methods was compared by using the incremental cost-effectiveness ratio (ICER). ICER is calculated by dividing the difference in total cost (incremental cost) by the difference in the chosen measure of health outcome or effect

(incremental effect) to provide a ratio of "extra cost per extra unit of health effect" for the more expensive therapy versus the alternative. Suboptimal sedation in our model would be associated with lower quality-adjusted life years (QALY) (27). Therefore, we used QALY as our health effect in the calculation of ICER.

2.5 Data analysis

Quantitative variables were compared by a 2-way ANOVA, testing with replication for all different devices. ANOVA testing was completed with WINKS WDA 7.0.9 (Texasoft, Dallas TX). The confidence level for hypothesis testing is 95%, and the α level is 0.05. For each dataset, the F-distribution and p value were determined. ANOVA was used for station setup time.

Kruskal Wallis tests were used to assess differences between types of practitioners and for setup time, flow rate accuracy, and participant ratings of each station. The Newman–Keuls multiple comparison test was used to assess statistical significance between stations for setup time and participant ratings. The statistical software used was SAS version 9.4 (SAS institute, Cary, NC).

For the qualitative, open-ended responses in the survey, data were analyzed by noting themes using content analysis as determined by 2 independent researchers.

3 Results

The study included 54 nurse, resident, and medical student volunteers (Table 3; Figure 2). Most participants were nurses, and the average number of years in practice was less than 10 but varied by vocation. The study included health professionals with diverse backgrounds, including previous experiences in low-resource settings around the world.

TABLE 3 Participant demographics.

Demographic variable	No. (%) of participants
Age range, years	
18–25	7 (12.96)
26–35	24 (44.44)
36–50	14 (25.93)
51–65	8 (14.81)
>65	1 (1.85)
Scope/Level of practice	
Nurse	34 (62.96)
Nurse anesthetist	11 (20.37)
Nurse (other)	23 (42.59)
Doctor	20 (37.04)
Medical student	11 (20.37)
Resident	9 (16.67)
Years of practice	
0	13 (24.07)
<1	4 (7.41)
1–10	20 (37.04)
11–20	9 (16.67)
>20	8 (14.81)
Gender	
Male	11 (20.4)
Female	43 (79.6)
Practical experience in a low-resource country	
Yes	6 (11.1)
No	48 (88.9)

3.1 Accuracy and precision of the infusion methods

A comparison of the results from all 5 stations showed no statistically significant differences in accuracy at various flow rates of 240 mL/h ($p = 0.878$), 120 mL/hour ($p = 0.093$), and 60 mL/h ($p = 0.105$; Table 4). At the highest infusion rate, the infusion pump had the greatest accuracy of flow, with a mean (SD) of 236 (21.7) mL/h, but this value was not statistically significant from that at other stations. The infusion pump and the manual flow regulator (226 [49.0] mL/h) appeared to have the highest precision.

When we analyzed the results based on residents and nurses alone, we found that at 240 mL/h, the differences in stations were significant ($p = 0.03$). In that analysis, the Alaris infusion pump's accuracy was similar to that of the DripAssist and the DripAssist combination stations, but it was significantly more accurate than drop counting and the manual flow regulator methods.

3.2 Setup times

Setup time differed significantly between stations ($p < 0.001$); the manual flow regulator was the least time consuming (mean [SD], 71 [56.2] seconds), and the combined DripAssist station was the most time consuming (365 [291.2] seconds; Table 5). Setup time for the manual flow regulator was not significantly different from that of the infusion pump, which had the second fastest time of 116 (77.9) seconds. The drop-counting method (225 [187.2] seconds) was the third fastest station to set up and was significantly different from the other 4 stations. The DripAssist station and the combined manual flow regulator and DripAssist station took the most time to set up (352 [240.1] seconds and 365 [291.2] seconds, respectively), but they were not significantly different from one another. Setup time for drop counting was significantly different between types of practitioners ($p = 0.001$), with nurses taking significantly less time than others.

The mean bag setup time was 100 s for those who set up the bag before setting up the infusion rate.

3.3 Participant ratings of the infusion methods

Ratings of understandability, operability, and perceived time consumption of the infusion methods differed significantly between stations ($p < 0.001$). The manual flow regulator was considered to be the most operable, most understandable, and least time consuming, and the DripAssist stations were considered the most time consuming (Table 5).

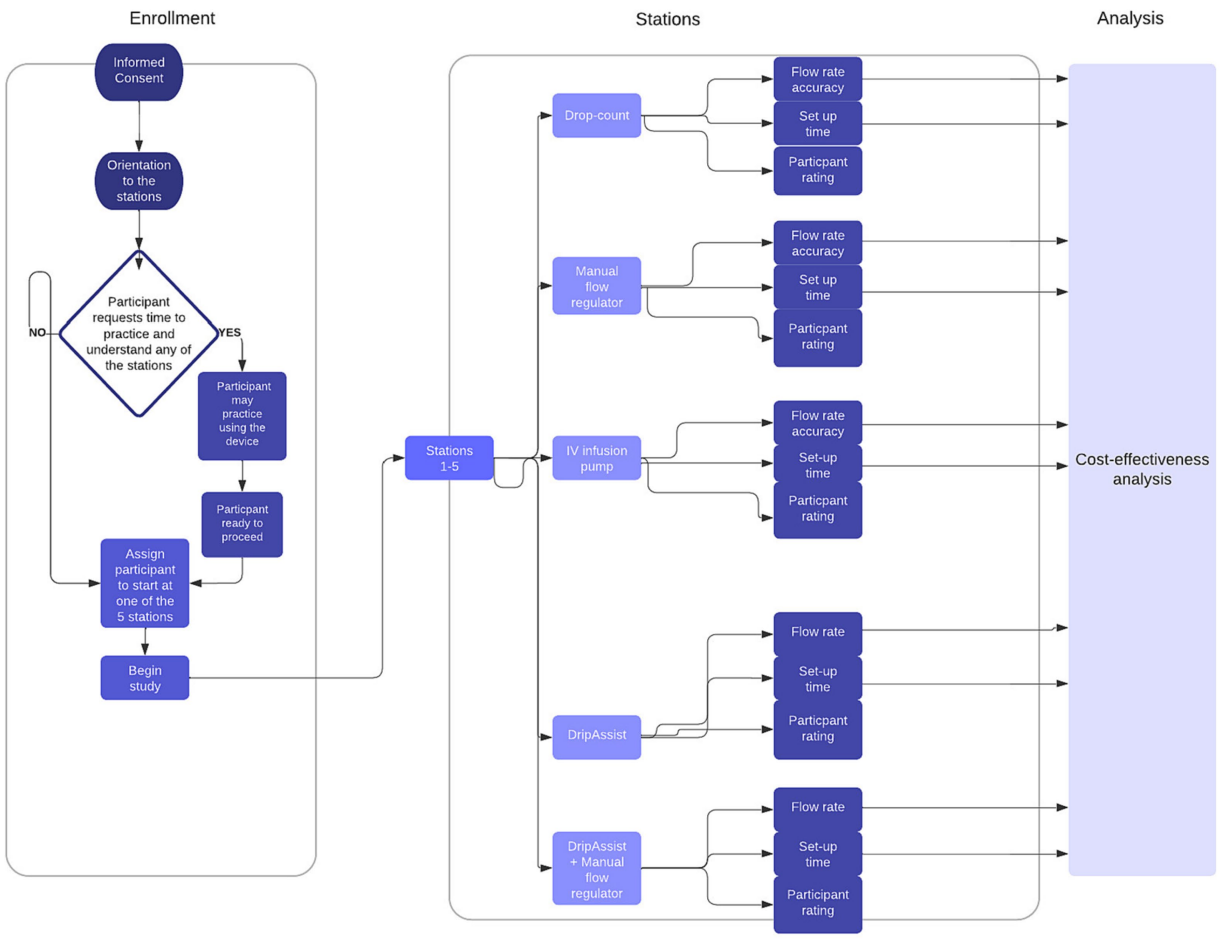

FIGURE 2
Study participant and data flow chart. Fifty-four participants ($n = 54$) enrolled and completed the study at all 5 stations and filled out a survey to rate each station. Data collected from participant flow rate accuracy and participant set-up time were used for cost-effectiveness analysis.

Understandability also varied among stations ($p < 0.001$). The drop-counting method and the manual flow regulator (stations 1 and 2) were rated the easiest to understand (mean [SD], 4.5 [0.92] and 4.8 [0.57], respectively) but were not statistically different from each other. The Alaris infusion pump and the DripAssist stations were the next easiest to understand (4.0 [1.2] and 3.8 [1.1], respectively) but were not statistically different from each other. The combined DripAssist and manual flow regulator station was the most difficult to understand (3.5 [1.3]) but was not statistically different from the DripAssist alone.

Analysis of operability ($p < 0.001$) showed that the manual flow regulator was the most operable device (4.7 [0.73]) by a statistically significant margin. The Alaris infusion pump was the second most easy station to operate (4.2 [1.1]), and this again was statistically different from other methods. Stations 1, 4, and 5 were the most difficult to operate (3.1 [1.6], 2.8 [1.2], and 3.0 [1.2], respectively) and were not statistically different from each other.

For the perceived time-consuming nature of the stations ($p < 0.001$), the manual flow regulator (station 2) was rated as the least time consuming (1.2 [0.58]), and this was statistically significant. The Alaris infusion pump (station 3) was perceived as the next least time-consuming device (1.7 [0.91]) and was also statistically significant. Stations 1, 4, 5 were rated as being the most time consuming, and the differences between these 3 were not statistically significant (3.3, [1.4], 3.7 [1.2], 3.4 [1.2], respectively).

3.4 Content analysis of participant survey comments

Several common themes emerged from participants' responses: perceived accuracy, time-consuming nature of method, willingness to use in low-resource settings, favorites, and suggestions for implementation in low-resource settings.

3.4.1 Perceived accuracy

Participants thought that the manual flow regulator was less accurate than other methods because the flow rates required estimates that were not on the device. For example, one participant mentioned that "the dial needs to be more accurate. Cannot tell if it is set up to 240. Numbers go from 200 to 250." Perceptions were mixed regarding whether the DripAssist was more accurate than drop counting. Although one participant preferred drop counting because the DripAssist "takes so long to set," another participant preferred the DripAssist, "especially in critical care situations in which the rate

TABLE 4 Comparison of flow rate accuracy among infusion methods.

Parameter	Drop counting	Manual flow regulator	Alaris IV infusion pump	DripAssist	DripAssist + manual flow regulator	*p* value
Flow rate goal: 240 mL/h						
Actual flow rate, mean (SD)	273.79 (155.79)	226.56 (49.04)	236.54 (21.7)	229.45 (73.22)	221.26 (62.82)	0.878
Mean deviation from the goal, %	14.08	−5.60	−1.44	−4.40	−7.81	
n	53	54	54	53	54	
Flow rate goal: 120 mL/h						
Actual flow rate, mean (SD)	124.83 (83.75)	118.86 (25.62)	117.16 (7.68)	108.25 (40.12)	109.22 (25.84)	0.093
Mean deviation from the goal, %	4.03%	−0.95%	−2.37%	−9.79%	−8.98%	
n	36	37	37	36	36	
Flow rate goal: 60 mL/h						
Actual flow rate, mean (SD)	65.38 (51.18)	55.41 (12.19)	57.78 (10.77)	61.71 (74.37)	56.82 (25.12)	0.105
Mean deviation from the goal, %	8.97%	−7.65%	−3.70%	2.85%	−5.30%	
n	34	34	36	35	34	

IV, intravenous; SD, standard deviation.

TABLE 5 Setup times and participant ratings for each infusion method.

Parameter	Drop counting	Manual flow regulator	Alaris IV infusion pump	DripAssist	DripAssist + manual flow regulator	*p* value
Setup time, seconds, mean (SD)[a]	224.83 (187.17)	70.76 (56.2)	116.07 (77.89)	351.83 (240.07)	365.39 (291.24)	<0.001
Participant rating						
Understandability, mean (SD)[b]	4.462 (0.917)	4.792 (0.567)	4.038 (1.176)	3.811 (1.128)	3.528 (1.31)	<0.001
Operability, mean (SD)[c]	3.094 (1.56)	4.692 (0.729)	4.204 (1.122)	2.843 (1.189)	3 (1.188)	<0.001
Time consuming nature, mean (SD)[d]	3.302 (1.367)	1.226 (0.577)	1.717 (0.907)	3.698 (1.17)	3.442 (1.243)	<0.001

IV, intravenous; SD, standard deviation.[a]$n = 54$ for all methods except for DripAssist, where $n = 53$.
[b]Rating scale was 1 to 5, with 5 being very easy to understand. $n = 53$ for all methods except for drop counting, where $n = 52$.
[c]Rating scale was 1 to 5, with 5 being very easy to operate. $n = 51$ for DripAssist and DripAssist + manual flow regulator; $n = 52$ for manual flow regulator; $n = 53$ for drop counting; $n = 54$ for Alaris IV infusion pump.
[d]Rating scale was 1 to 5, with 5 being very time consuming. $n = 53$ for all methods except for DripAssist + manual flow regulator, where $n = 52$.

needs to be very accurate - it's better than nothing. However if I was just infusing fluids, I might just drop count."

3.4.2 Time consuming

Participants found the 2 DripAssist stations to be the most time consuming. One participant remarked that it was "painful," and another pointed out that it "requires no movement," because the device is motion-sensitive during setup. Yet another participant wrote, "I wanted to like the DripAssist, and it was more convenient than counting drops, but it is also time consuming trying to get the exact number. It's easier for a nurse to come by and do a quick check" on the flow rate "to make sure the rate has not changed due to patient movement compared to drop count." In comparison with other methods, "the Alaris was the fastest but using the DripAssist and manual regulator together were easy to operate and not that time consuming with practice." Although most participants thought that the manual flow regulator alone was least time consuming, participants who liked the combination station thought that more experience with the DripAssist could decrease the time for setup and allow the accuracy to approach that of the Alaris infusion pump.

3.4.3 Willingness to use in low-resource settings

Many participants stated that all of the devices could be used in a low-resource setting and that they can help improve the safety of medications administered. For example:

- "If people are taught" and oriented to the new technologies, such implementation "will be a great way to learn and it will be useful in a low-resource setting."
- These various technology methods "will help patients get more medications in a safe and timely manner."

3.4.4 Favorites

Participants had a variety of favorites among the 5 stations for different reasons. Manual drop counting was favored because it was the "most fun." The manual flow regulator was favored because it was not as motion-sensitive as the DripAssist and was "not bad." The DripAssist station was favored, with reservation, because participants "would have loved this in the ICU," but "there may be a lot of [number] rounding." The combination of the DripAssist and manual flow regulator was favored by some because it "made me feel more confident." The

combination station was the least favorite for some participants because "positioning is key for the DripAssist" and it was "overwhelming because you have to go back and forth between devices."

3.4.5 Suggestions for implementation in low-resource settings

Participants' suggestions for the manual flow regulator and the DripAssist ranged from improving efficiencies with the flow of patient care to using one infusion method as a backup to the other. The following are the most noteworthy feedback points gathered from the participants:

- Caution is recommended with "checking and changing tubing," as this is one of the most important steps.
- Because of its motion sensitivity, "changes in gravity (higher/lower IV bag) affect the DripAssist" accuracy measurements.
- One suggestion targeted cost savings with DripAssists. The participant recommended running the DripAssist "to spot check-- like after running for a few minutes." This use could allow low-resource settings to purchase fewer DripAssists.
- Another participant further suggested that in the healthcare setting, the staff could "just undershoot the rate and then supplement if necessary" as another cost-saving measure.
- A concern was raised with the manual flow regulator with regard to "[changing] the device for each patient."

3.5 Cost-effectiveness analysis

The results of our study indicated that all infusion methods reached levels of accuracy that were comparable to the gold standard of the IV infusion pump ($p = 0.8$). Therefore, each method can achieve an optimal sedation state to reduce in-hospital mortality and increase quality of life. Therefore, we assigned QALY = 1 for all methods. The infusion pump would be the most expensive method in both Senegal and India, and the manual flow regulator would be the least expensive (Table 6). Therefore, the incremental cost-effectiveness ratio, or ICER, helps to relate the cost to the effectiveness of the type of IV method as illustrated below. A negative ICER indicates cost savings.

Comparison of manual flow regulator to drop counting.
ICER = 409.56–411.77/1 QALY = −$2.21 per QALY in Senegal.
ICER = 113.26–110.04/1 QALY = $3.22 per QALY in India.

Comparison of DripAssist to drop counting.
ICER = 707.76–411.77/1 QALY = $295.99 per QALY in Senegal.
ICER = 410.57–110.04/1 QALY = $300.53 per QALY in India.

TABLE 6 Total cost per method per patient.

Infusion method	Total cost ($)**	
	Senegal	India
Drop counting	411.77	110.04
Manual flow regulator	409.56	113.26
Alaris IV infusion pump	2404.92	2108.16
DripAssist	707.76	410.57
DripAssist + manual flow regulator	711.85	414.63

IV, intravenous. **Costs are based on a 3-day stay in the ICU.

Comparison of DripAssist/manual flow regulator to drop counting.
ICER = 711.85–411.77/1 QALY = $300.08 per QALY in Senegal.
ICER = 414.63–110.04/1 QALY = $304.59 per QALY in India.
Comparison of IV infusion pump to DripAssist.
ICER = 707.76–2404.92/1 QALY = −1697.16 per QALY in Senegal.
ICER = 410.57–2108.16/1 QALY = −1697.59 per QALY in India.

Comparison of IV infusion pump to DripAssist/manual flow regulator.
ICER = 711.85–2404.92/1 QALY = −1693.07 per QALY in Senegal.
ICER = 414.63–2108.16/1 QALY = −1693.53 per QALY in India.

Comparison of IV infusion pump to manual flow regulator.
ICER = 409.56–2404.92/1 QALY = −1995.36 per QALY in Senegal.
ICER = 113.26–2108.16/1 QALY = −1994.90 per QALY in India.

With the exception of the IV infusion pump, all methods met acceptable cost-effectiveness thresholds for implementation in Senegal (adjusted for purchasing power parity: $73–$1,166; actual $34–$544) or India (adjusted for purchasing power parity: $416–$2,781; actual: $115–$770) (25). The manual flow regulator appeared to have the highest cost-effectiveness. The DripAssist also met acceptable levels of cost-effectiveness in both countries and theoretically yielded cost savings when compared with implementing the IV infusion pump.

4 Discussion

In this study, we examined new devices for delivering IV infusions, compared their accuracy and precision, and evaluated their cost-effectiveness in low-resource settings. Additionally, we assessed the perceptions of these devices among a diverse group of healthcare workers. These participants offered additional insights into the use of the technologies in low-resource settings.

Both the DripAssist and the manual flow regulator are portable, superior low-cost alternatives to drop counting. The manual flow regulator alone was best understood and easiest to operate for the participants and had a high level of precision, making this a very favorable option for a low-resource setting. Although the DripAssist/manual flow regulator combination increased accuracy compared with manual drop counting, this combination was the most difficult to use and most time consuming, making it a less favorable option for a low-resource setting. Comments from participants suggested that the DripAssist could achieve as much accuracy as the infusion pump but that it was very sensitive, position-dependent, and more time consuming than other systems tested (Table 7).

An additional consideration was that setup time for drop counting differed significantly between types of practitioners ($p < 0.001$), with nurses taking significantly less time than others. The setup time factored into our cost analysis with physician and nurse wages. Furthermore, because the Alaris infusion pump is only offered in English, language may present as another barrier to implementation in non-English speaking countries, such as Senegal.

Based on these results, we believe that healthcare providers can adapt these devices to their practice environments and thereby improve the safety of rate-sensitive IV medications over the traditional method of drop counting without significant strain on electricity, time, or personnel resources.

TABLE 7 Comparison of methods based on desired metrics.

Method	Accuracy	Precision	Actual setup time	Perceived setup time	Perceived understanding	Perceived operability	Cost-effectiveness
Drop counting	+	+	+++	++	+++	+++	++
Manual flow regulator	+++	++++	+++++	+++++	+++++	+++++	+++++
Alaris IV infusion pump	+++++	++++	++++	+++++	++++	+++	+
DripAssist	++++	+	+	+	++	++	+++
DripAssist/ manual flow regulator	++++	++	+	+	++	+	+++

More + marks in a category indicates more favorable metrics for that method. IV, intravenous.

4.1 Accuracy and healthcare worker perceptions

A key finding in this study is the similarity in accuracy between the different infusion methods. As mentioned previously, the DripAssist has demonstrated accuracy and can be used in low-resource settings such as in prehospital locations and military medicine (10, 11). In addition, Couperus et al. (11) assessed the perceptions of healthcare workers who compared the DripAssist to drop counting and infusion pumps and concluded that the DripAssist was easier to use than either drop counting or infusion pumps and that the DripAssist can be accurate in a low-resource setting. Participants in our study believed the DripAssist to be as accurate as the infusion pump, but they did not find it to be easier to operate than either the infusion pump or drop counting. Of note, a disadvantage of the free drop method was the decrease in the rate as the IV bag decreases in volume. Nevertheless, participants thought that with practice, DripAssists may become easier to use. Participants cited the motion sensitivity of the DripAssist as the reason for it being the most time consuming and least operable of the devices tested.

Another consideration is the possibility of low infusion rates. In one study by Vieira *et al,* low infusion rates were shown to cause a startup delay, that is, the period between the start of the infusion at a desired infusion rate and the actual delivery of the medication. Startup delay not only delays the delivery of medication to the patient, it also creates a discrepancy between the delivered volume as recorded by the pump and the volume that is actually delivered to the patient. The startup delay was smaller at higher infusion rates. Accuracy was not affected at any of the flow rates, though total volume delivered may have been affected (28).

Additionally, our study demonstrated a significant difference in flow rate accuracy ($p = 0.03$) among the more experienced healthcare workers, namely nurses and residents. Flow rate accuracy of the DripAssist was statistically similar to that of the infusion pump and statistically different from those of the manual flow regulator and drop-counting methods. Thus, when looking to apply these methods in low-resource settings, it is important to note that nurses and residents are the backbone of the workforce. Nevertheless, medical students also learned the setup and had infusion method ratings similar to those of other health professionals.

Other considerations are that in Dakar, Senegal, the manual flow regulator is commonly used, whereas in India, manual counting of drops or milliliters is most commonly used. Despite unfamiliarity with the manual flow regular and its lower accuracy, participants demonstrated higher precision with this device than with other devices. This finding implies that healthcare settings, including those in low-resource areas, may use other metrics for deciding between methods.

4.2 Cost

We conducted a cost-effectiveness analysis of the 5 methods for India and Senegal as representative low-resource settings in sub-Saharan Africa and in South Asia. We included health-related costs, worker-related costs, and the direct costs of each infusion method. The health measure of interest was based on QALY after sedation in the ICU. The infusion pump appeared to be least cost-effective and the manual flow regulator appeared to be most cost effective in a low-resource environment (demonstrated for both Senegal and India). With the exception of the IV infusion pump, all methods met globally acceptable cost-effectiveness thresholds (29). It is interesting to note that in Senegal, ventilator use does not factor into the pay structure. It could be that the use of ventilators lags behind owing to lack of training; thus most ventilators in the country are not being used. Another reason could be that the use of ventilators is factored into the "oxygen need" of the patients. Conversely, in India, use of ventilators is a large contributor to cost, making it very expensive to keep a patient on the machine for more than 2 days.

4.3 Limitations and future areas of research

This study had some limitations. For example, not every participant had to set up an IV bag from scratch, reducing the sample size for this metric. The study was not conducted in low-resource settings, but rather in high-resource institutions, and it was not conducted at the patient bedside. It is possible that results for flow rate may differ in clinical settings, especially in low-resource areas. Finally, our cost-effectiveness analysis addressed only one outcome that was based on the accuracy of sedation flow rates, which we found differs minimally between methods. Although statistical significance was not demonstrated, statistical significance may differ from clinical significance of the variation in flow rates demonstrated in this study.

Further study of the manual flow regulator may be warranted to determine how many times it can be reused, how long on average it takes to break, and how regularly it should be tested for accuracy. In addition, future studies of the experimental methods used here should be conducted as a clinical study in a low-resource clinical setting. Such a study could be conducted in Sierra Leone, as Johns Hopkins sent 30 DripAssists there in 2020 to bolster their critical care capacity. Lastly, the devices should be trialed at other flow rates and with other fluids or medications, perhaps tailored

to the most frequently used rate-sensitive medications in these settings.

4.4 Conclusion

Both the DripAssist and manual flow regulator are portable, superior low-cost alternatives to drop counting. The combination of the 2 devices has accuracy similar to that of manual drop counting. However, this combination was the most difficult and most time-consuming method tested in the study. The manual flow regulator alone was most understood and easiest to operate by healthcare worker participants and was determined to be the most cost effective in low-resource settings. The DripAssist followed as the next most cost-effective method. These methods can be considered for implementation in acute care environments when sedation infusions are part of IV therapy. Healthcare providers can easily adapt these devices to their practice environments and improve the safety of rate-sensitive IV medications without significant strain on electricity, time, or personnel resources.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the Johns Hopkins School of Medicine Institutional Review Board and the Howard Community College Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

OT: Conceptualization, Data curation, Formal analysis, Investigation, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. SA: Data curation, Formal analysis, Investigation, Validation, Writing – original draft, Writing – review & editing, Project administration. IE: Investigation, Supervision, Writing – review & editing. SW: Data curation, Investigation, Methodology, Writing – review & editing. FD: Data curation, Validation, Writing – review & editing. GD: Data curation, Formal analysis, Investigation, Project administration, Writing – review & editing. OO: Data curation, Writing – review & editing, Project administration, Visualization. KS: Data curation, Investigation, Supervision, Writing – review & editing. EA: Data curation, Investigation, Supervision, Writing – review & editing. VK: Data curation, Investigation, Writing – review & editing. JS: Conceptualization, Investigation, Supervision, Writing – review & editing. YS: Data curation, Investigation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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References

1. Kazory A, Ronco C, McCullough PA. SARS-CoV-2 (COVID-19) and intravascular volume management strategies in the critically ill. *Proc (Bayl Univ Med Cent)*. (2020) 33:370–5. doi: 10.1080/08998280.2020.1754700

2. Claure-Del Granado R, Mehta RL. Fluid overload in the ICU: evaluation and management. *BMC Nephrol*. (2016) 17:109. doi: 10.1186/s12882-016-0323-6

3. World Health Organization. WHO coronavirus (COVID-19) dashboard. (2022). Available at: https://covid19.who.int/. Accessed November 22, 2022.

4. Poston JT, Patel BK, Davis AM. Management of critically ill adults with COVID-19. *JAMA*. (2020) 323:1839–41. doi: 10.1001/jama.2020.4914

5. Loner C, Acquisto NM, Lenhardt H, Sensenbach B, Purick J, Jones C, et al. Accuracy of intravenous infusion flow regulators in the prehospital environment. *Prehosp Emerg Care*. (2018) 22:645–9. doi: 10.1080/10903127.2018.1436208

6. Song Y, Wang W, Zhang L, Sha L, Lu G. Optimization of the intravenous infusion workflow in the isolation ward for patients with coronavirus disease 2019. *Int J Nurs Sci*. (2020) 7:148–52. doi: 10.1016/j.ijnss.2020.03.009

7. Kress JP, Pohlman AS, O'Connor MF, Hall JB. Daily interruption of sedative infusions in critically ill patients undergoing mechanical ventilation. *N Engl J Med*. (2000) 342:1471–7. doi: 10.1056/NEJM200005183422002

8. DiaMedical: Advancing Training & Simulation for the next generation of medical professionals. Available at: Diamedicalusa.com (Accessed: 14 September 2023).

9. Atanda O, West J, Stables T, Johnson C, Merrifield R, Kinross J. Flow rate accuracy of infusion devices within healthcare settings: a systematic review. *Ther Adv Drug Saf*. (2023) 14:20420986231188602. doi: 10.1177/20420986231188602

10. BuyMedical.Com: Wholesale medical supplies. Available at: buymedical.com (Accessed: 14 September 2023).

11. Buonora MJE. Management of Gravity Intravenous Infusions in an austere environment using the DripAssist infusion rate monitor. *AANA J*. (2019) 87:65–70.

12. Couperus K, Kmiecik K, Kang C. IV DripAssist: an innovative way to monitor intravenous infusions away from an outlet? *Mil Med*. (2019) 184:322–5. doi: 10.1093/milmed/usy365

13. Li J, Dong P, Lai Y, Qin X, Bai J, Wang H, et al. Intelligent infusion controller with a physiological information feedback function. *Technology and health care: Official J European Society for Engineer Med*. (2020) 28:37–46. doi: 10.3233/THC-209005

14. Juarez A, Maynard K, Skerrett E, Molyneux E, Richards-Kortum R, Dube Q, et al. AutoSyP: a low-cost, low-power syringe pump for use in low-resource settings. *Am J Trop Med Hyg*. (2016) 95:964–9. doi: 10.4269/ajtmh.16-0285

15. Skerrett E, Kommwa E, Maynard K, Juarez A, Mataya R, Richards-Kortum R, et al. Evaluation of a low-cost, low-power syringe pump to deliver magnesium sulfate intravenously to pre-eclamptic women in a Malawian referral hospital. *BMC Pregnancy Childbirth*. (2017) 17:191. doi: 10.1186/s12884-017-1382-9

16. Ouedraogo NS, Schimanski C. Energy poverty in healthcare facilities: a "silent barrier" to improved healthcare in sub-Saharan Africa. *J Public Health Policy*. (2018) 39:358–71. doi: 10.1057/s41271-018-0136-x

17. Barghouth A, Brower A, Larson J, Shaw G. Beyond access: What does electricity mean for healthcare facilities in Senegal? (2021). Accessed June 3, 2023. Available at: https://www.climatelinks.org/blog/beyond-access-what-does-electricity-mean-healthcare-facilities-senegal#:~:text=The%20lack%20of%20electricity%20restricts,far%20too%20many%20healthcare%20workers

18. Carayon P, Wetterneck TB, Hundt AS, Ozkaynak M, Ram P, DeSilvey J, et al. Observing nurse interaction with infusion pump technologies In: K Henriksen, JB Battles and ES Markset al, editors. *Advances in patient safety: From research to implementation (volume 2: Concepts and methodology)*. Rockville (MD): Agency for Healthcare Research and Quality (US) (2005)

19. Manrique-Rodríguez S, Sánchez-Galindo AC, de Lorenzo-Pinto A, González-Vives L, López-Herce J, Carrillo-Álvarez Á, et al. Implementation of smart pump technology in a paediatric intensive care unit. *Health Informatics J*. (2015) 21:209–22. doi: 10.1177/1460458213518058

20. Fox J. E. The science of usability testing. Bureau of Labor Statistics. Accessed May 24, 2023. (2015). Available at: nces.ed.gov/fcsm/pdf/C2_Fox_2015FCSM.pdf

21. Kulkarni AP, Divatia JV. A prospective audit of costs of intensive care in cancer patients in India. *Indian J Crit Care Med*. (2013) 17:292–7. doi: 10.4103/0972-5229.120321

22. Schedule of charges, Mangalam Hospital, (2022).

23. Clinique Madeleine, Clinique Casahous, Hopital Principal, Hôpital Aristide Le Dantec, Clinique Pasteur.

24. Les pharmacies et al Pharmacie nationale d'approvisionement.

25. Wade KA, Diop ZB, Diop EHN, Niang B, Sow A, Kounta MB, et al. Facteurs Predictives de Mortalite en reanimation a L'hopital principal de Dakar/Senegal. *Mali Med*. (2022) 37:25–9.

26. Sessler CN, Gosnell MS, Grap MJ, Brophy GM, O'Neal PV, Keane KA, et al. The Richmond agitation-sedation scale: validity and reliability in adult intensive care unit patients. *Am J Respir Crit Care Med*. (2002) 166:1338–44. doi: 10.1164/rccm.2107138

27. American Thoracic Society. Understanding costs and cost-effectiveness in critical care: report from the second American Thoracic Society workshop on outcomes research. *Am J Respir Crit Care Med*. (2002) 165:540–50. doi: 10.1164/ajrccm.165.4.16541

28. Vieira NM, Pires MPO, Crespo GB, Nascimento LPP, Peterlini MAS, Pedreira MLG. Start-up delay in syringe infusion pumps with different rates and priming techniques of intravenous sets. *Rev Gaucha Enferm*. (2022) 43:e20210071. doi: 10.1590/1983-1447.2022.20210071.en

29. Woods B, Revill P, Sculpher M, Claxton K. Country-level cost-effectiveness thresholds: initial estimates and the need for further research. *Value Health*. (2016) 19:929–35. doi: 10.1016/j.jval.2016.02.017

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Bridging the mismatch: observing the introduction of new anesthesia technology for a low-resource environment

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Objective: The objective of this study was to examine the impact of the introduction of the Universal Anaesthesia Machine (UAM), a device designed for use in clinical environments with limited clinical perioperative resources, on the choice of general anesthesia technique and safe anesthesia practice in a tertiary-care hospital in Sierra Leone.

Methods: We introduced an anesthesia machine (UAM) into Connaught Hospital, Freetown, Sierra Leone. We conducted a prospective observational study of anesthesia practice and an examination of perioperative clinical parameters among surgical patients at the hospital to determine the usability of the device, its impact on anesthesia capacity, and changes in general anesthesia technique.

Findings: We observed a shift from the use of ketamine total intravenous anesthesia to inhalational anesthesia. This shift was most demonstrable in anesthesia care for appendectomies and surgical wound management. In 10 of 17 power outages that occurred during inhalational general anesthesia, anesthesia delivery was uninterrupted because inhalational anesthesia was being delivered with the UAM.

Conclusion: Anesthesia technologies tailored to overcome austere environmental conditions can support the delivery of safe anesthesia care while maintaining fidelity to recommended international anesthesia practice standards.

KEYWORDS

Africa, Sierra Leone, global health, anesthesia, low-resource environments

1 Introduction

Safe general anesthesia is a drug-induced reversible condition that includes specific behavioral and physiological traits—unconsciousness, amnesia, analgesia, and akinesia—with concomitant stability of the autonomic, cardiovascular, respiratory, and thermoregulatory systems (1). Anesthesia delivery systems are essential intraoperative life support devices used to achieve these goals in surgical patients. Design advances in anesthesia technology have introduced complex features that enhance patient management in high-resource countries but render such devices impractical and unsafe in resource-poor locations that experience frequently interrupted electrical supply, inconsistent access to compressed oxygen (2) and consumables such as carbon dioxide (CO_2)-absorbing granules (2), and little or no biomedical maintenance support. These constraints hinder the global goal to improve access to safe surgical and anesthesia care as described by the Lancet Commission on Global Surgery and the World Health Assembly in 2015 (3).

The Universal Anaesthesia Machine (UAM®) (Gradian Health Systems Inc. New York, United States) was designed to overcome these constraints by providing a source of concentrated oxygen from ambient air, low-resistance vaporizers, and one-way expulsion of CO_2 in the absence of CO_2-absorbing granules. The machine could thus enhance the capacity to provide safe and consistent anesthetic care for surgical patients in low-resource conditions.

The objective of this study was to examine the safety and impact of introducing the UAM® into an austere clinical environment with limited perioperative resources. Specifically, we examined the effect of the addition of the UAM® on the practice of total intravenous anesthesia (TIVA) techniques for general anesthesia in a tertiary-care hospital in Sierra Leone. We hypothesized that if local anesthesia providers had access to a reliable, safe, and effective anesthesia delivery system, we would observe a shift among general anesthesia cases from TIVA techniques to increased use of inhalational agents. We also examined the performance of the UAM® in the presence of environmental constraints and reviewed its effects on intraoperative care, postoperative sedation, and analgesic levels after its deployment.

2 Methods

2.1 Study setting

This study took place at Connaught Hospital in Freetown, Sierra Leone, West Africa. Connaught Hospital is a tertiary-level government hospital with 275 beds that serves as a national referral center, providing all health services except maternal and non-surgical pediatric healthcare. Here, 10–15 cases are performed in the operating rooms.

2.2 Ethics

The study approval was obtained from the Sierra Leone Ethics and Scientific Review Committee and our Institutional Review Board. All participants provided consent prior to enrolling in the study. The funding company did not provide any oversight with respect to data review or choice of data collection. They did not see or influence study plans or results, nor did they influence study design, or review outcomes prior to or during abstract and manuscript generation. Safeguards against research influence were incorporated within a memorandum of understanding with the company.

2.3 Study design

We conducted a prospective observational study of anesthesia practice among all anesthesia providers at Connaught Hospital (10 nurse anesthetists and 1 physician anesthetist), examining perioperative clinical parameters among a convenience sample of surgical patients. Observed procedures and enrolled patients were those scheduled to receive surgical care on weekdays (M-F) between 8:30 a.m. and 4:00 p.m. and consented to participate in the study, respectively. We designed and piloted the perioperative data collection forms among anesthesia providers at the Johns Hopkins Hospital, Baltimore, Maryland, United States, and subsequently modified these tools in-country to ensure contextually appropriate data variables and minimize data collection ambiguity. Data were collected at the study site over a period of 25 months (June 2012 to July 2014). Baseline clinical anesthesia practice was determined through direct observation of care and documentation of perioperative tasks by anesthesia providers in a preceding observational exercise from June 2012 to February 2013 (pre-UAM® deployment) (4), after which we introduced the UAM® to the hospital. Device deployment was accompanied by a 1-week training course for all anesthesia care providers and biomedical technicians. The training involved basic principles related to the provision of general anesthesia and the use of the UAM. Given the introduction of new UAMs, we worked closely with Gradian Health for a detailed step-by-step walk-through of the use of the UAMs. We continued the observation of anesthesia practice after device introduction for 18 months from February 2013 to August 2014.

We trained seven Sierra Leonean research assistants, including two research nurses, on research methodology, operating room etiquette, and other relevant tasks. These research assistants were also trained to assess clinical care, including vital sign monitoring, and clinical parameters such as pain and consciousness level of patients in the perioperative period. Intraoperative data collection took place from Monday to Friday over a period of 2 years, except on hospital-sanctioned holidays when elective surgical cases were not performed. Research nurses monitored vital signs at designated times in the postoperative period. The Johns Hopkins-based research team (consisting of US-based clinicians with public health expertise) supervised research assistant training and data collection directly until they obtained a kappa statistic of agreement ≥ 0.7 (5).

Postoperatively, we followed the clinical status of observed cases to hospital discharge or to postoperative day 30 through examination of hospital ward records. The research nurses conducted direct patient clinical assessments for recovery from anesthesia and surgery in the first 72 postoperative hours among a convenience sample of consented patients.

2.4 Materials

2.4.1 Anesthesia devices

- The UAM® can be classified as a low-resource optimized anesthesia machine in that it is designed for environments that must contend with power interruptions, compressed oxygen shortages, and biomedical technician limitations. It is an electric anesthesia delivery system with an incorporated high-capacity oxygen concentrator capable of providing a flow of 10 L/min with 95% inspired oxygen delivery to the patient. It utilizes a low-resistance draw-over vaporizer system that permits the combination of continuous flow and/or draw-over anesthesia for varying conditions encountered in resource-challenged, austere environments. Although the UAM® can use compressed cylinder oxygen or pipeline oxygen sources to deliver oxygen and inhaled agents, the low-resistance draw-over vaporizer can function without compressed gases via egress of room air into the system, providing anesthesia delivery to the patient in the absence of compressed gases or electrical power. It is an oxygen sensor that analyzes the inspired oxygen concentration delivered to the patient and displays this on a monitor with a 10-h battery backup. The UAM® model used in this study is designed for spontaneous and/or manually assisted ventilation (with manual bellows, all UAMs® are delivered with an attached multifunction cardiac monitor from a different manufacturer). The UAM® has CE certification for safe use by the European Union, and the system was approved for use by the Sierra Leone Ministry of Health and the IRB for the country. The UAM® was already in use in the United Kingdom at the time of commencing the study. The Johns Hopkins University School of Medicine created an NGO organizational agreement with the authorities in the country and had a memorandum of understanding (MOU) with the authorities in Sierra Leone. The government authorized the UAMs to be used in-country before the study.
- The Compact-3 (manufacturer unknown) is a type of Boyle's anesthesia machine [a continuous-flow anesthesia machine with five basic elements: (1) a high-pressure supply of gases, (2) pressure gauges on oxygen cylinders, with pressure-reducing valves, (3) flow meters, (4) metal and glass vaporizer bottle for ether, and (5) a breathing system] (6). The Compact-3 was in residence during this study although its utility was intermittent due to frequent mechanical dysfunction.
- A Glostavent® Anaesthesia Machine (Diamedica (United Kingdom) Limited, Grange Hill Industrial Estate, Bratton Fleming, Barnstaple, Devon, EX31 4UH, United Kingdom) was present but malfunctioned (oxygen concentrator and ventilator) and was retired 3 months after the deployment of the UAM®.

The Glostavent can also be classified as a low-resource optimized anesthesia machine.

Patient monitoring devices used during data collection included non-invasive blood pressure monitors, Lifebox® pulse oximeters (Lifebox, London, United Kingdom), and electronic thermometers with disposable slips.

2.5 Data collection

Using anesthesia data records, research assistants documented anesthesia-related tasks from patient preoperative arrival to postoperative patient handoff. Surgical procedure and patient demographic data were obtained from the operation list or anesthesia/surgery records. Some variables such as American Society of Anesthesiologists (ASA) clinical status scores and elective or emergent status of the case required verbal confirmation from the anesthesia provider.

Anesthesia-related tasks (e.g., airway management), anesthesia technique, vital signs, and electrical and mechanical disturbances in the operating room were recorded. Timestamps for events such as power failures and anesthesia/surgery start and stop times were collected. Appropriate precautions were taken to avoid distracting providers from patient care by suspending questions during active delivery of care and complying with operating room etiquette. In the 30-day postoperative period, data collectors ascertained the admission status of patients using the following categories: a return to the operating theater within the 30-day period, hospital discharge, or death. Research nurses documented vital signs at the following postoperative times: 1, 2, and 4 h and 1, 2, and 3 days. The Wong–Baker Faces Pain Scale was used to assess self-reported postoperative pain scores, and the Richmond Agitation Sedation Scale was used to determine sedation level in the initial 4-h postoperative period (7, 8). We also reviewed operating room logbooks to determine anesthesia caseload and technique, including those performed outside study observation hours.

With an α-error set to 0.05, a modest treatment effect (20% reduction in ketamine TIVA-only cases), and a true failure rate for experimental subjects as 0.4, we needed to enroll 518 experimental subjects and 518 control subjects (for a minimum sample size = 1,036 cases) to be able to reject the null hypothesis that the failure rates for experimental and control subjects are equal with probability (power) of 0.9. Our sample size justification, based on an uncorrected chi-squared test, was appropriate for this study.

Anesthesia records and follow-up data were scanned into data-secure computers, and the information was abstracted for entry into a FileMaker Pro database (FileMaker, Inc., Santa Clara, CA, United States) and subsequently Microsoft Excel (Microsoft Corp., Redmond, WA, United States). Using STATA 12 software (StataCorp LP, College Station, TX, United States), data analyses included frequency distributions, chi-square test, Wilcoxon rank-sum test, two-sample test of proportions, and linear and logistic regression to compare and examine the relationship between variables, using a statistical significance set at a p-value of <0.05.

3 Results and discussion

According to hospital operating room records (Table 1), 2,764 anesthetic cases were performed between June 2012 and July 2014. Of these, 850 took place before the introduction of the UAM®, and 1,917 took place after the introduction of UAM®. Table 2 describes the distribution of anesthesia techniques.

We reviewed all general anesthesia techniques performed in pre-and post-UAM® study phases and, after controlling for age and

TABLE 1 Description of anesthetic cases (Connaught Hospital operating room registry).

Characteristics[a]	Total	Pre-UAM	Post-UAM	Chi-square
	N = 2,764 (%)	*N* = 850 (%)	*N* = 1914 (%)	(df) χ^2 *p*-value
Patient demographics				
Female, *n* (%)	839 (30.35)	281 (33.49)	558 (29.2)	χ^2 (2) 6.324, 0.04
Male, *n* (%)	1910 (69.10)	562 (66.12)	1,348 (70.4)	
Age ≤ 1 year, *n* (%)	150 (5.21)	38 (4.5)	112 (5.9)	χ^2 (3) 5.0233, 0.17
Age > 1 to <18 years, *n* (%)	600 (21.7)	185 (21.8)	415 (21.7)	
Age 18–65 years, *n* (%)	1798 (65.1)	549 (64.6)	1,249 (65.3)	
Age > 65 years, *n* (%)	216 (7.8)	78 (9.2)	138 (7.2)	
Surgical categories				
ENT, *n* (%)	65 (2.35)	18 (2.1)	47 (2.5)	χ^2 (9) 14.2, 0.116
General surgery, *n* (%)	1988 (71.9)	629 (74.0)	1,359 (71.0)	
Gynecology, *n* (%)	18 (0.65)	4 (0.5)	14 (0.7)	
Neurosurgery, *n* (%)	37 (1.34)	6 (0.7)	31 (1.62)	
Orthopedics, *n* (%)	259 (9.37)	88 (10.4)	171 (8.9)	
Plastic surgery/facial and reconstructive, *n* (%)	35 (1.26)	10 (1.18)	25 (1.3)	
Thoracic surgery, *n* (%)	3 (0.11)	0 (0)	3 (0.16)	
Urology, *n* (%)	321 (11.61)	89 (10.5)	232 (12.1)	
Procedure not documented, *n* (%)	38 (1.37)	6 (0.7)	32 (1.7)	

ENT, ear, nose, and throat; UAM, Universal Anaesthesia Machine.
[a]Categories may not add up to 100% due to undocumented cases.

surgical categories, observed a 1.6-fold increase ($p = 0.001$, 95% CI [1.19–2.14]) in the odds of inhalational anesthesia administration compared to TIVA, in the post-UAM® period. This shift from TIVA (predominantly ketamine) to inhalational anesthesia was most demonstrable in anesthesia care for patients undergoing appendectomies and surgical wound management (Table 3).

3.1 Directly observed anesthesia cases

In the post-UAM® phase, we observed 870 cases of perioperative anesthesia care (Table 4), 45.5% of all cases performed. In total, 20 of these cases were described as emergent by local providers.

3.2 Intraoperative period

Among regional cases converted to general anesthesia (Table 4), inhalational agents were utilized 54% of the time. Providers monitored blood pressure in 612 (70.3%) patients, pulse oximetry in 827 (95.1%), electrocardiography in 30 (3.5%), temperature in 23 (2.7%), and capnography in 10 (1.15%). Blood pressure was more likely to be measured in patients older than 18 years of age, χ^2 (2, $N = 870$) $p < 0.001$.

We observed 343 incidents of intraoperative tachycardia (heart rate > 100 beats/min for ≥10 min in patients >12 years). The proportion of patients who experienced tachycardia did not differ among patients who received inhalational anesthesia from the UAM® and those whose anesthesia was delivered by another machine, $z = 1.96$, $p = 0.05$.

The portable free-standing oxygen concentrator onsite had a maximum delivery capacity of 5 L/min and had been improvised to connect to the Compact-3 anesthesia machine. All observations where oxygen delivery flow rates were greater than 5 L/min occurred in cases involving the UAM® or an oxygen tank. Compressed cylinder oxygen was unavailable for >50% of the duration of the total observational period, and, when available, there was no reliable method to confirm the oxygen concentration in the cylinder.

The UAM® was used to deliver inhalational anesthesia in 287 cases, and for supplemental oxygen delivery in 38 cases that did not involve the use of inhalational anesthesia. The choice of anesthesia machine did not affect the duration of anesthesia or surgical care (Table 5).

We recorded 27 instances of power outages ranging from 1 min to 90 min in duration. In total, 17 of these occurred during inhalational anesthesia delivery, of which 10 were administered with the UAM®. There were no interruptions in the latter as the UAM® immediately reverted to room air (with inhalational anesthetic), while ventilation in other cases was continued with an Ambu bag® (without inhalational anesthetic). There were two occasions of reported anesthesia equipment-related malfunction. On investigation, neither originated from the machine. One incident was a power surge, which damaged fuses in the UAM® as a result of surge protector removal prior to the event.

Biomedical technicians at Connaught Hospital replaced the fuses within hours of discovery, and the machine returned to full service. In the second event, the oxygen monitor displayed an alarm for the replacement of the oxygen sensor. This was initially mistaken for low oxygen concentration readings and occurred 11.5 months after the

TABLE 2 Description of all performed anesthesia techniques (operating room registry).

	Total	PreUAM	Post-UAM	Z	*p* value
	n = 2,764	*n* = 850 (%)	*n* = 1914 (%)		
Total general anesthesia (GA) cases	1,610	475 (55.9)	1,135 (59.3)	−1.67	0.094
Scheduled GA	1,551	445 (52.4)	1,106 (57.8)	−2.64	0.008
Spinal converted to GA	49	25 (2.94)	24 (1.25)	3.11	0.002
Local converted to GA	10	5 (0.59)	5 (0.26)	1.32	0.186
Anesthesia agents used					
Inhalational anesthesia	890	234 (27.5)	656 (34.3)	−3.53	<0.001
Halothane	890	234 (27.8)	656 (34.3)	−3.53	<0.001
Total intravenous anesthesia	719	240 (28.2)	479 (25.0)	1.77	0.077
Ketamine	658	225 (26.5)	433 (22.6)	2.22	0.026
Propofol	26	13 (1.5)	13 (0.07)	2.01	0.045
Thiopental	31	2 (0.2)	29 (1.5)	−3.02	0.002
Regional techniques					
Spinal anesthesia	821	242 (28.5)	579 (30.3)	−0.96	0.339
Local anesthesia	299	108 (12.7)	191 (10)	2.13	0.033
Anesthesia technique not documented	6	1 (0.1)	5 (0.3)		

A two-sample test of proportions was used. UAM, Universal Anaesthesia Machine.

installation of the machine. The manufacturer recommends replacing the oxygen sensor after 12 months.

3.3 Postoperative outcomes and mortality

A Wilcoxon rank-sum test revealed a difference in hours 2 and 4 pain scores between TIVA and inhalational anesthesia cases (Table 6).

Linear regression showed this to be significant at only hour 4, with pain scores lower in inhalational cases by −0.83, 95% CI [−1.37 to 0.29], $p = 0.003$. The rate of consciousness recovery did not differ between the two groups in hours 1, 2, or 4 postoperatively. Anesthesia machine differences used did not demonstrate a change in postoperative pain or level of consciousness scores at the 1-, 2-, or 4-h monitoring times (Table 6). In total, 30-day postoperative mortality among observed cases was 2.3% (20 patients), with a risk ratio of 1.66, 95% CI [0.7–3.9], $p = 0.24$, compared to the pre-UAM® period. We were unable to determine the postoperative status of 21 patients during the study period. These were either cases that were canceled mid-procedure or cases that we were unable to follow for the designated follow-up period owing to the 2014 Ebola Viral Hemorrhagic outbreak. Among inhalational anesthesia cases, we found no relation between mortality and the type of anesthesia machine used, $\chi^2(1, N = 454) = 0.16$, $p = 0.691$.

4 Discussion

In 2008, the World Health Organization commenced the Global Initiative on Health Technologies to promote the design of innovative technologies adapted for use in resource-limited settings, among other goals. This initiative was borne out of a recognition of the mismatch between available health technology and health infrastructure in many low-resource locations (9, 10). A 2011 study of medical devices in developing countries revealed that, on average, 38.3% of medical technologies in such locations were out of service (8). These findings have been attributed to a lack of appropriate training and infrastructure as well as technological mismanagement (11, 12). The oxygen sensors continue to be a problem. More recent studies involving the UAM aimed to examine simulation methodologies to adopt the use of the UAM (13–15). In the case of anesthesia technology, other factors that may be responsible for the premature retirement of devices include unreliable electricity, absence of compressed gases, insufficient biomedical expertise for maintenance, and ill-suited inhalational agent vaporizers. Although three anesthesia machines were used in varying degrees during the project, six anesthesia machines were physically present in the operating suite areas (Table 6).

As described above, we identified a significant increase in the use of inhalational anesthetic agents following the installation of the UAM®. Among failed regional anesthesia cases, the proportion converted to inhalational anesthesia relative to TIVA was significantly higher after the UAM® was introduced into the environment, $z = 4.56$, $p \leq 0.001$.

The routine practice prior to the UAM® often included holding parts of the anesthesia machine together. In the absence of active maintenance agreements with anesthesia machine manufacturers, these machines were repaired by biomedical technicians and anesthesia staff through improvisation and inventive use of available materials or parts from other machines, which required securing them together so that they do not fall apart. Other challenges included unreliable oxygen delivery to the patient.

TABLE 3 General anesthesia use among the 10 most common surgical cases performed (operating room registry).

Procedure	Total performed in pre- and post-period	Pre-UAM				Post-UAM			Odds of INH as the choice of GA, pre-*vs* post UAM		
		Total pre-UAM	GA	INH, *n* (%)	TIVA, *n* (%)	Total post-UAM	GA	INH, *n* (%)	TIVA, *n* (%)	OR	95% CI	*p*-value
Hernia repair	918	261	107	77 (72)	30 (28)	657	289	207 (71.6)	82 (28.4)	0.98	0.58–1.65	0.947
Appendectomy	213	62	53	18 (34)	35 (66)	151	112	61 (54.5)	51 (45.5)	2.33	1.12–4.89	0.014
Laparotomy	205	62	62	30 (48.4)	32 (51.6)	143	139	71 (51.1)	68 (48.9)	1.11	0.59–2.12	0.724
Prostatectomy	108	40	6	2 (33.3)	4 (66.7)	68	0	0	0	NA	NA	NA
Wound debridement/ exploration	103	24	18	2 (11.1)	16 (88.9)	79	64	25 (39.1)	39 (60.9)	5.13	1.04–48.99	0.026
Lumpectomy	87	45	29	12 (41.4)	17 (58.6)	42	26	13 (50.0)	13 (50.0)	1.42	0.43–4.7	0.522
Amputation	81	26	6	2 (33.3)	4 (66.7)	55	12	5 (41.7)	7 (58.3)	1.43	0.13–21.41	0.732
Urethral calibration	80	15	15	1 (6.7)	14 (93.3)	65	57	4 (7.0)	53 (93.0)	1.06	0.09–55.7	0.962
Urethral repair	78	21	5	1(20)	4(80)	57	8	6(75.0)	2 (25.0)	12	0.54–686.48	0.053
Hydrocelectomy	76	25	10	4 (40)	6(60)	51	19	14 (73.7)	5 (26.3)	4.2	0.64–28.96	0.076

GA, general anesthesia; INH, inhalational anesthesia; TIVA, total intravenous anesthesia; OR, odds ratio; CI, confidence interval; NA, not available.

While power outages are relatively rare events, when they occur, then there is an increased risk to patients and barriers to the safe use of anesthesia. These events can be stressful and challenging, potentially leading to avoidance of the use of general anesthesia. With a system specifically designed for use in constrained environments, the UAM® allows for more consistently reliable delivery of general anesthesia and possibly more comfort for providers to utilize general anesthesia in these challenging environments.

During the study period, the facility experienced a number of unforeseen challenges that had adverse effects on surgical productivity. These events included shortages of inhalational anesthetics, periodic interruptions to compressed oxygen production and availability, autoclave breakdowns, and a shutdown of the operating room as a result of flooding from extreme weather. Although power outages were frequent, these were mitigated by the presence of a functional generator. Some of these impediments to surgical delivery could not be ameliorated by the UAM®, whereas some were specifically overcome by qualities of the UAM®. These include:

- efficient oxygen concentrator: able to administer 10 L/min of 95% oxygen, advantageous during the study period as compressed oxygen was unavailable >50% of the time.
- an oxygen analyzer: reliably measures the percentage of oxygen available to the patient by the oxygen concentrator. Before the study, we had been unable to confirm the concentration of oxygen in cylinders because the hospital lacked an oxygen analyzer. This monitor is powered by a trickle charge from the main power supply. This safety feature is critical to monitoring inspired oxygen content, especially during simultaneous power outages and compressed oxygen shortages.
- a low-pressure vaporizer: It enables continued inhalational anesthesia delivery during the simultaneous absence of compressed oxygen and electricity. In these events, the UAM® reverts to room air draw-over anesthetic mode, sustaining the patient at 21% oxygen. There were 10 incidents of power outages during inhalational anesthesia delivery with the UAM®.
- a halothane vaporizer: Although halothane has been largely replaced by isoflurane in high-income countries because of related side effects, it is still widely used in many African nations owing to its low cost (16, 17). The UAM® is outfitted with two detachable vaporizers: one each for halothane and isoflurane. Halothane and ether were the only available inhalational anesthetics.
- a one-way valve system: It prevents rebreathing and provides unidirectional gas flow. In this environment, CO_2-absorbing granules are often not available or replaced. End-tidal CO_2 ($ETCO_2$) levels are not routinely measured, and hypercapnia may go undiagnosed with rebreathing systems. Although two capnography monitors were available in the operating suites, $ETCO_2$ was rarely monitored as described in the Results section. The manufacturer recommends the use of passive scavenging of exhaust gases from the system. We did not observe adherence to these guidelines. Reasons for not using capnography included its unavailability in Sierra Leone at the time, the fact that capnography was not part of the UAM monitoring package, and,

TABLE 4 Anesthesia cases/techniques performed on directly observed cases (directly observed by the team).

Anesthesia cases	Total	Pre-UAM	Post-UAM
	n = 1,374	*n* = 504 (%)	*n* = 870 (%)
ASA classification			
ASA I	867	340 (67.5)	527 (60.6)
ASA II	405	131 (26)	274 (31.5)
ASA III	31	10 (2.0)	21 (2.4)
ASA IV	2	2 (0.4)	0 (0)
ASA unknown	69	21 (4.2)	48 (5.5)
Anesthesia technique			
General anesthesia[a]	845	287 (56.9)	558 (64.1)
Inhalational	676	205 (40.7)	471 (54.1)
TIVA	169	82 (16.3)	87 (10)
Regional anesthesia	493	193 (38.3)	310 (35.6)
Spinal	364	138 (27.4)	226 (26)
Local	127	55 (10.9)	84 (9.7)
Monitored anesthesia care	25	24 (4.8)	1 (0.1)
Intraoperative change in anesthesia technique	76	29 (5.8)	47 (5.4)
Regional converted to general anesthesia	71	28 (5.6)	43 (4.9)
Airway management			
Endotracheal intubation	391	112 (22.2)	279 (32.1)
Laryngeal mask airway	28	11 (2.2)	17 (2.0)
Oropharyngeal airway +/− facemask	297	117 (23.2)	180 (20.7)
Facemask	387	212 (42.1)	175 (20.1)
None	378	159 (31.5)	219 (25.2)

ASA, American Society of Anesthesiologists; TIVA, total intravenous anesthesia; UAM, Universal Anaesthesia Machine.
[a]Includes regional anesthesia cases converted to general anesthesia.

even when capnography monitors were introduced, the nurse anesthetists did not adopt its use because they were never formally trained in it, and the leadership was reluctant due to not having a good knowledge base for using it.

4.1 Implications

Among all cases, we identified an increase in the proportion of general anesthetics performed, with the greater percentage being inhalational anesthesia, rather than ketamine TIVA. In debrief interviews, anesthesia providers described the UAM® as "simple," "convenient," and "straightforward." Multiple users recommended the inclusion of an automated ventilator mode to ease the workload of manual ventilation during long cases. Subsequent UAM® models designed since the conclusion of the study include a mechanical ventilator.

4.2 Perioperative outcomes

We did not detect a difference in the occurrence of adverse events between UAM® and non-UAM® cases. With respect to postoperative pain, we identified a slight decrease in pain scores at hour 4 among inhalational cases compared to TIVA. There were no differences in analgesic administration. This fact is noteworthy; as halothane has minimal to no analgesic properties, it was often co-administered with boluses of intravenous anesthetics or narcotic analgesics, especially during anesthetic induction. Such co-administration occurred in 342 cases. It is possible that more reliable depth of anesthesia and quality general anesthesia may have led to less noxious stimulation during the surgery and may have led to pre-emptive analgesia, and thus difference in pain scores.

4.3 Limitations

While the training program can be viewed as a confounding and contributing factor in the outcome of the study, from its inception, the study design made *a priori* assumptions that training on clinical use and maintenance were essential elements to the acceptance and use of the UAM in common clinical practice. The training program does not overcome the obstacles of oxygen availability, stable electricity, and maintenance ease. However, it would be unethical to deploy novel technology in the absence of relevant training.

5 Conclusion

Anesthesia technologies tailored to overcome austere environmental conditions have the ability to deliver safe anesthesia care while maintaining fidelity to recommended international anesthesia practice standards. In this study, we observed the *in situ* use

TABLE 5 Perioperative care duration (minutes) among inhalational anesthesia cases administered by UAM and non-UAM machines.

	Inhalational UAM			Inhalational non-UAM					
	M	SD	CI	M	SD	CI	df	*t*-test	*p*-value
Anesthesia duration[a]	61.6	36.4	57.4–65.9	59.4	39.4	53.7–65.2	466	−0.62	0.53
Anesthesia care duration[b]	71	39.3	66.4–75.6	68.4	41	62.4–74.4	466	−0.68	0.49
Emergence time[c]	10.2	11.5	8.8–11.5	10.4	11.5	8.7–12.03	466	0.16	0.87
Surgery duration[d]	41.3	30.7	37.7–44.9	38.3	29.5	34.02–42.7	466	−1.03	0.31

UAM, Universal Anaesthesia Machine; M, mean; SD, standard deviation; CI, confidence interval; df, degrees of freedom.
[a]Anesthesia duration: commencement of induction to completion of surgery (wound dressing applied).
[b]Anesthesia care duration: Time from first contact with the patient to time when the patient is handed off for transfer to the ward or immediate postoperative discharge.
[c]Emergence time: Time from surgery end to when the patient is handed off for transfer to the ward or immediate postoperative discharge.
[d]Surgery time: Time from incision to wound dressing application or surgeon communicates completion.

TABLE 6 Pain and level of consciousness scores among inhalational cases (by type of anesthesia machine) and general anesthesia cases 1–4 h postoperatively.

Postoperative time	Type of anesthesia machine	*N*	Mean	Wilcoxon rank-sum test		Type of GA	*N*	Mean	Wilcoxon rank-sum test	
				Z	*p*-value				*Z*	*p*-value
Postoperative pain										
1 h	Non-UAM	110	0.77	0.28	0.78	Inhalational	304	0.79	0.94	0.35
	UAM	194	0.8			TIVA	65	0.85		
2 h	Non-UAM	108	1.45	0.43	0.67	Inhalational	289	1.4	2.06	0.039
	UAM	181	1.37			TIVA	65	1.92		
4 h	Non-UAM	71	2.45	−0.87	0.38	Inhalational	198	2.58	2.76	0.006
	UAM	127	2.65			TIVA	51	3.41		
Level of consciousness										
1 h	Non-UAM	143	−0.53	0.20	0.84	Inhalational	366	−0.56	0.16	0.87
	UAM	223	−0.56			TIVA	71	−0.07		
2 h	Non-UAM	135	−0.27	0.26	0.79	Inhalational	342	−0.29	−0.11	0.91
	UAM	207	−0.30			TIVA	71	−0.35		
4 h	Non-UAM	94	−0.03	−0.23	0.82	Inhalational	256	−0.02	−1.24	0.22
	UAM	162	−0.01			TIVA	52	−0.12		

UAM, Universal Anaesthesia Machine; GA, general anesthesia; TIVA, total intravenous anesthesia.

of a low-resource optimized anesthesia machine, the Universal Anaesthesia Machine. In an environment with multiple unfavorable conditions, we were able to determine that the UAM® provided efficient and reliable anesthetic delivery without adverse outcomes. Since UAM® introduction at Connaught Hospital, a shift in ketamine-TIVA anesthetic administration to inhalational general anesthesia was observed. While there is no basis for identifying one anesthetic technique as superior to another, there are advantages to having options for different types of anesthesia for different types of cases and different types of patients.

The UAM® functioned without any significant mechanical problems and provided a reliable source of oxygen via the concentrator with an oxygen sensor/monitor to ensure adequate oxygen delivery during surgery. The use of devices that are designed to function in challenging austere environments, require minimal maintenance, and utilize local sources of replacement parts, combined with training of providers and technicians, should theoretically provide reliable, safe, and efficient care in these settings. Currently, there are two UAMs at Connaught that are frequently used. The maintenance team has been able to fix any problems that arise. Capnography is also being used. Pursuant to the 2015 World Health Assembly's Resolution on Surgery and Anesthesia Care (3), it is imperative to examine the technological resources available to perioperative providers working in constrained conditions and strive to engineer appropriate technology for safe perioperative care in their environments.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Johns Hopkins Institutional Review Board; Sierra Leone Ethics and Scientific Review committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JS: Writing – original draft, Writing – review & editing, Investigation, Methodology. RK: Writing – review & editing, Formal analysis, Investigation. OT: Writing – review & editing. AC: Data curation, Writing – review & editing, Methodology. EJ: Writing – review & editing, Investigation, Methodology. MR: Writing – review & editing, Investigation. MK: Writing – review & editing, Methodology, Investigation. HN-W: Writing – review & editing. ED: Writing – review & editing. BL: Funding acquisition, Investigation, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Evers A, Crowder M. Cellular and molecular mechanisms of anesthesia In: PG Barash, BF Cullen, RK Stoelting, M Cahalan and MC Stock, editors. *Clinical anesthesia*. New York: Lippincott Williams & Wilkins (2006), 95–114.

2. Ezi-Ashi TI, Papworth DP, Nunn JF. Inhalational anaesthesia in developing countries. Part I. The problems and a proposed solution. *Anaesthesia*. (1983) 38:729–35. doi: 10.1111/j.1365-2044.1983.tb12195.x

3. World Health Assembly resolution A68/15. Strengthening emergency and essential surgical care and Anaesthesia as a component of universal health coverage, May 22nd (2015).

4. Koka R, Chima AM, Sampson JB, Jackson EV, Ogbuagu OO, Rosen MA, et al. Anesthesia practice and perioperative outcomes at 2 tertiary care hospitals in Freetown, Sierra Leone. *Anesth Analg*. (2016) 123:213–27. doi: 10.1213/ANE.0000000000001285

5. McHugh ML. Interrater reliability: the kappa statistic. *Biochem Med (Zagreb)*. (2012) 22:276–82. doi: 10.11613/BM.2012.031

6. Watt M. The evolution of the Boyle apparatus 1917-67. *Anaesthesia*. (1968) 23:103–18. doi: 10.1111/j.1365-2044.1968.tb00015.x

7. Sessler CN, Gosnell MS, Grap MJ, Brophy GM, O'Neal PV, Keane KA, et al. The Richmond agitation-sedation scale: validity and reliability in adult intensive care unit patients. *Am J Respir Crit Care Med*. (2002) 166:1338–44. doi: 10.1164/rccm.2107138

8. Garra G, Singer AJ, Taira BR, Chohan J, Cardoz H, Chisena E, et al. Validation of the Wong-baker FACES pain rating scale in pediatric emergency department patients. *Acad Emerg Med*. (2010) 17:50–4. doi: 10.1111/j.1553-2712.2009.00620

9. World Health Organization. Medical devices: managing the mismatch: an outcome of the priority medical devices project (2010), pp. 14–15.

10. Howitt P, Darzi A, Yang GZ, Ashrafian H, Atun R, Barlow J, et al. Technologies for global health. *Lancet*. (2012) 380:507–35. doi: 10.1016/S0140-6736(12)61127-1

11. Perry L, Malkin R. Effectiveness of medical equipment donations to improve health systems: how much medical equipment is broken in the developing world? *Med Biol Eng Comput*. (2011) 49:719–22. doi: 10.1007/s11517-011-0786-3

12. Pena-Mohr J. Distributing and transferring medical technology. A view from Latin America and the Caribbean. *Int J Technol Assess Health Care*. (1987) 3:281–91. doi: 10.1017/S026646230000057X

13. Tomobi O, Toy S, Ondari M, Lee S, Nelson-Williams H, Koroma M, et al. Evaluating rapid-cycle deliberate practice versus mastery learning in training nurse anesthetists on the universal anaesthesia machine ventilator in Sierra Leone. *J Educ Perioper Med*. (2021) 23:E658. doi: 10.46374/volxxiii_issue1_sampson

14. Sampson JB, Lee BH, Koka R, Chima AM, Jackson EV, Ogbuagu OO, et al. Human factors evaluation of the universal Anaesthesia machine: assessing equipment with high-fidelity simulation prior to deployment in a resource-constrained environment. *J Natl Med Assoc*. (2019) 111:490–9. doi: 10.1016/j.jnma.2019.03.005

15. Chima AM, Koka R, Lee B, Tran T, Ogbuagu OU, Nelson-Williams H, et al. Medical simulation as a vital adjunct to identifying clinical life-threatening gaps in austere environments. *J Natl Med Assoc*. (2018) 110:117–23. doi: 10.1016/j.jnma.2017.12.003

16. Halliday NJ. Problems facing the visiting anesthesia team in an underdeveloped nation and possible solutions. *J Craniofac Surg*. (2015) 26:1066–8. doi: 10.1097/SCS.0000000000001629

17. Splinter W. Halothane: the end of an era? *Anesth Analg*. (2002) 95:1471. doi: 10.1097/00000539-200212000-00001

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Ultrasound assessment of diaphragmatic dysfunction in non-critically ill patients: relevant indicators and update

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Diaphragm dysfunction (DD) can be classified as mild, resulting in diaphragmatic weakness, or severe, resulting in diaphragmatic paralysis. Various factors such as prolonged mechanical ventilation, surgical trauma, and inflammation can cause diaphragmatic injury, leading to negative outcomes for patients, including extended bed rest and increased risk of pulmonary complications. Therefore, it is crucial to protect and monitor diaphragmatic function. Impaired diaphragmatic function directly impacts ventilation, as the diaphragm is the primary muscle involved in inhalation. Even unilateral DD can cause ventilation abnormalities, which in turn lead to impaired gas exchange, this makes weaning from mechanical ventilation challenging and contributes to a higher incidence of ventilator-induced diaphragm dysfunction and prolonged ICU stays. However, there is insufficient research on DD in non-ICU patients, and DD can occur in all phases of the perioperative period. Furthermore, the current literature lacks standardized ultrasound indicators and diagnostic criteria for assessing diaphragmatic dysfunction. As a result, the full potential of diaphragmatic ultrasound parameters in quickly and accurately assessing diaphragmatic function and guiding diagnostic and therapeutic decisions has not been realized.

KEYWORDS

diaphragm, diaphragm dysfunction, ultrasound, ultrasound indicators, ultrasound application, perioperative period, non-critically ill patients

Introduction

The diaphragm is a thin, dome-shaped muscle that separates the thoracic and abdominal cavities (Figure 1). In a healthy adult, it is only 2–3 millimeters thick. Despite its small size, it is responsible for 60–80% of ventilation needs (1, 2). The diaphragm plays a crucial role in the respiratory muscle pump, aiding in coughing and the expulsion of secretions (3). It also reduces the risk of lung infections. Both mechanical ventilation and damage to the phrenic nerve can lead to diaphragmatic dysfunction (DD), characterized by an imbalance between the diaphragm's ability to provide enough negative pressure for vital capacity and the workload imposed upon it. DD during mechanical ventilation (MV) is recognized as an important factor influencing clinical outcomes (4–9), and prolonged mechanical ventilation can result in decreased diaphragm thickness.

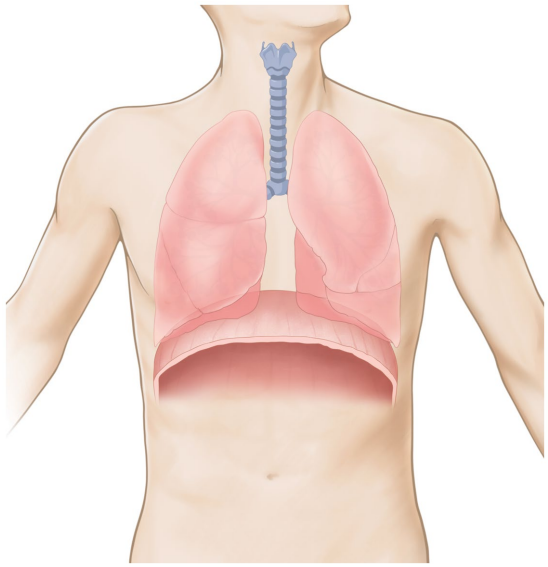

FIGURE 1
Location and morphology of the diaphragm.

Studies have shown that for every 10% reduction in diaphragm thickness (DT) in critically ill patients, intensive care unit (ICU) mortality and hospitalization rates increase by 1.55- and 1.66-fold, respectively (10–12). More than 10 million patients worldwide require MV therapy each year, with approximately 30% of these patients needing extended ventilator use (13). Wasting atrophy of the diaphragm is a contributing factor to respiratory failure, and it is important to note that clinical symptoms may not occur until one's diaphragmatic strength has decreased to 30% of its capacity (14). Early detection of DD is crucial, as early intervention can improve symptoms (15–17). However, there has been a gradual increase in the number of studies on non-critical patients in recent years, this suggests that diaphragmatic dysfunction is also common among perioperative non-critical patients. Therefore, the objective of this review was to analyze and summarize the indicators and criteria for ultrasound assessment of DD in non-critical patients. To achieve this, databases such as PubMed and Web of Science were searched with the aim of providing a reliable basis for clinical use.

Currently, there is no uniformity in the selection of ultrasound indicators and thresholds for diaphragmatic dysfunction, although there is an international expert consensus that a diaphragmatic excursion (DE) of less than 2 cm is the criterion for diagnosing diaphragmatic dysfunction (18), no article has been found to use this criterion. As a result, the main problem faced by clinicians is the lack of standardized criteria, while ultrasound is the preferred diagnostic tool for diaphragm dysfunction, a wide range of indicators and thresholds are summarized in the literature, which significantly affects clinicians' judgment and delays early intervention.

Ultrasound evaluation of diaphragmatic dysfunction

The gold standard for the diagnosis of diaphragmatic dysfunction is phrenic nerve stimulation and transdiaphragmatic pressure assessment (7, 19), however, these methods are invasive and not clinically applicable (20). In recent years, ultrasound has become a widely-used noninvasive technology (21), it allows noninvasive, reproducible, and safe assessment of the diaphragm's anatomy and function (22–26). Two commonly used ultrasound modes are B-Mode and M-Mode (27, 28), and the key indicators of diaphragm function assessed by ultrasound include DE, diaphragm thickening fraction (DTF), and DT.

Measurements of DT and DTF require the use of a high-frequency linear ultrasound transducer (3–12 MHz). The patient should be in a semi-recumbent position, and the probe should be placed in the midaxillary line at ribs 8–10, perpendicular to the intercostal space. In B-Mode, the diaphragm can be visualized as a three-layered structure, with the upper hyperechoic layer being the pleura, the lower layer being the peritoneum, and the middle layer being the diaphragm (29) (Figures 2A,B). In contrast, DE measurements are performed using a low-frequency abdominal convex probe (3–5 MHz), the patient should be positioned at a 45-degree semi-recumbent angle, and the ultrasound probe should be placed parallel to the right costal margin at the right midclavicular line, using the transverse section of the liver as an acoustic window. Alternatively, the probe can be placed perpendicular to the costal margin to obtain a longitudinal section of the liver (Figures 2C,D). It is also possible to obtain diaphragm images at different interfaces using liver vessels as markers, however, this method is not commonly used (Figure 3). In B-Mode, the high echo shadow covering the liver surface represents the diaphragm, switching to M-Mode allows for the observation of the diaphragm waveform synchronized with the respiratory cycle (Figure 4B). On the left side, the probe is placed at the 8–10th rib along the midaxillary line, parallel to the intercostal spaces, the other methods are the same as for the right side (Figure 4A) (29). Ultimately, ultrasound is clinically reproducible (32) and has become an essential tool for most clinicians, its overall measurement failure rate has decreased from 27% a decade ago to 0.7% today, demonstrating the effectiveness of ultrasound technology (33).

Table 1 provides a comparison of the materials and methods used for assessing diaphragmatic dysfunction across the literature. Diaphragmatic ultrasound is widely used to assess diaphragmatic dysfunction in various medical conditions, including neuromuscular diseases (46, 47), chronic respiratory diseases, and conditions requiring intensive care (18, 21, 48), it helps clinicians diagnose and monitor conditions such as diaphragmatic paralysis or weakness. Additionally, diaphragmatic dysfunction can significantly impact weaning outcomes, thus, ultrasound can provide essential insights to predict the success of extubation (40, 49, 50). Ultrasound can also be used to counsel patients with respiratory failure in making decisions about the necessity and potential success of noninvasive ventilation (51). Additionally, it plays a crucial role in enhancing the understanding of ventilator management among patients with coronavirus 2019 disease (52).

In anesthesiology, diaphragm ultrasound helps determine the residual muscle relaxation in patients under general anesthesia, addressing the complexities and interferences associated with the gold standard train-of-four ratio procedure (53), it is possible to predict and prevent postoperative pulmonary complications in surgical patients, including those undergoing heart surgery, thoracic surgery, and upper abdominal surgery (34, 54–58). In rehabilitation medicine, diaphragm thickness is positively correlated with patients' functional scores and functional independence scores before and after rehabilitation, suggesting that diaphragm thickness can influence patients' rehabilitation progress (59). Overall, diaphragm ultrasound

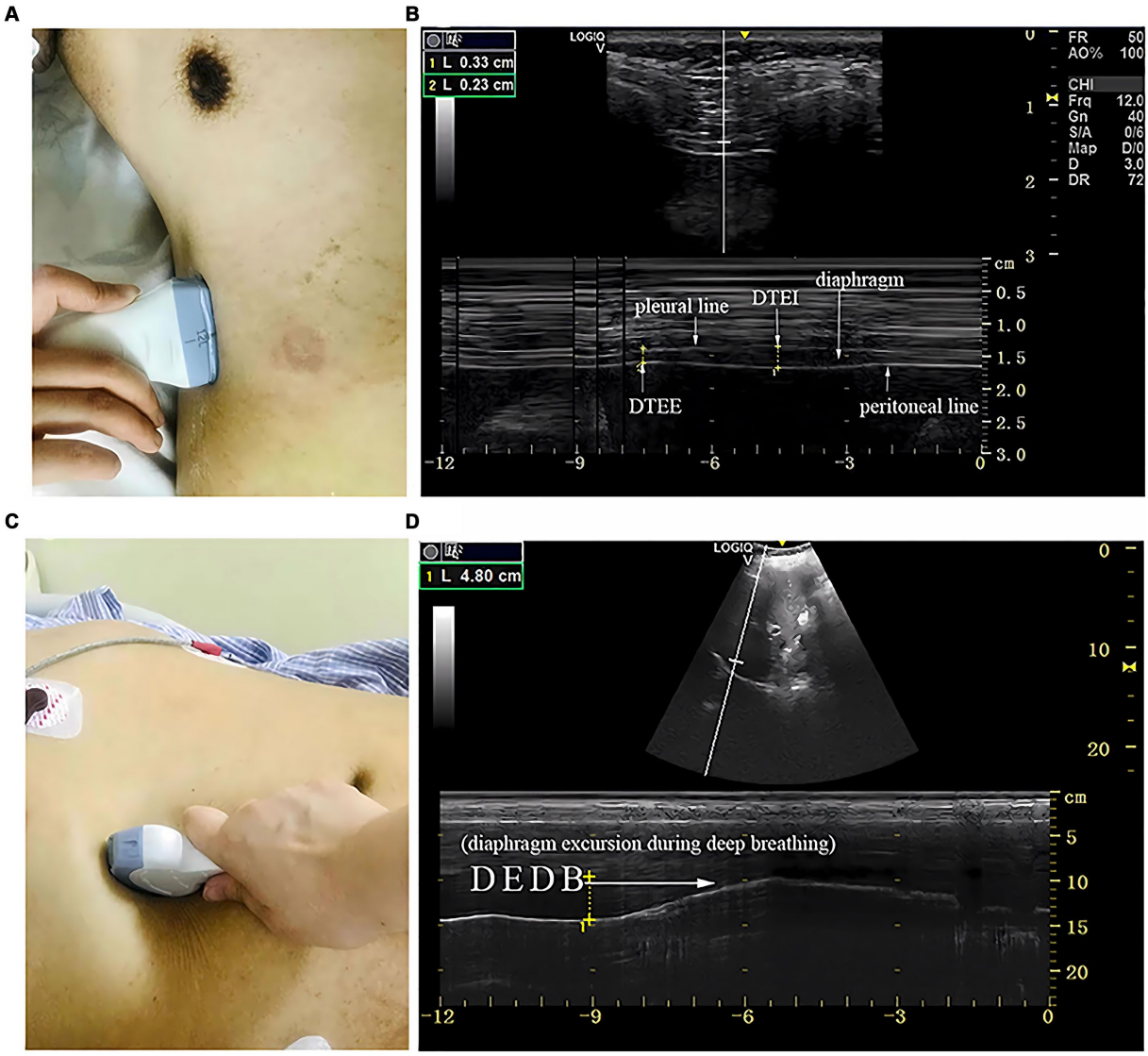

FIGURE 2
The measurement of diaphragmatic thickness and excursion. **(A)** A 10–15 MHz probe was placed at the zone of apposition. **(B)** The non-echogenic layer between the yellow markers indicates the thickness of the diaphragm at the end of expiration and inspiration. **(C)** A 2–5 MHz curved-array probe was placed under the costal margin. **(D)** The bright line indicates diaphragmatic excursion during deep breathing. DTEE, diaphragm thickness at end-expiratory; DTEI, diaphragm thickness at end-inspiration; DEDB, diaphragmatic excursion during deep breathing (30).

has become a valuable tool in routine clinical practice, particularly for assessing diaphragmatic function in various medical conditions.

Perioperative ultrasound assessment of diaphragmatic dysfunction

Preoperative assessment of DD

Ultrasound is often used in clinical trials in patients undergoing elective surgery, normal healthy people, and critically ill patients (32, 48, 55). Notably, patients with bilateral DD experience a significant 75% reduction in forced vital capacity (FVC) (60), it can also lead to impaired lung ventilation, resulting in pneumonia or atelectasis (61–63). Therefore, preoperative DD not only affects a patient's quality of life but also impacts their prognosis and survival after surgery. Huh et al. demonstrated a significant association between preoperative DD and prolonged postoperative mechanical ventilation in lung transplantation patients using a DE measurement of <1 cm (odds ratio [OR]: 2.79, $p < 0.05$). Additionally, patients with preoperative DD had a 15% probability of developing persistent DD 1 year after surgery (64).

Tension pneumoperitoneum is a known cause of DD, and a case report series assisted surgeons in identifying the cause of postoperative respiratory failure in patients by using an ultrasound measurement of diaphragm thickness ratio(diaphragm thickness of maximal inspiration/that of end-expiration) < 1.2 (65), despite diaphragm thickness ratio normalization after 10 days, delayed diagnosis negatively impacts the patient's prognosis, and DD in patients undergoing cardiac surgery is one of the most overlooked complications (66). A maximum preoperative DTF <38.1% is

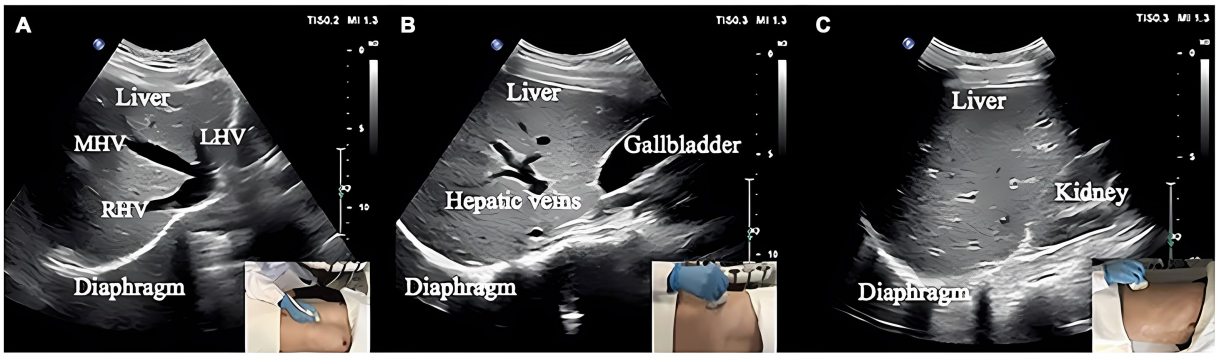

FIGURE 3
(A) Section I: Oblique section of the lower right costal arch through the second hepatic portal with the left hepatic vein (LHV), middle hepatic vein (MHV), and right hepatic vein (RHV) as anatomical markers. **(B)** Section II: Oblique section of the right intercostal passage through the first hepatic portal with the inferior vena cava, hepatic vein, and gallbladder as anatomical markers. **(C)** Section III: Sagittal section of the liver and right kidney with the right kidney and hepatorenal space as anatomical markers (31).

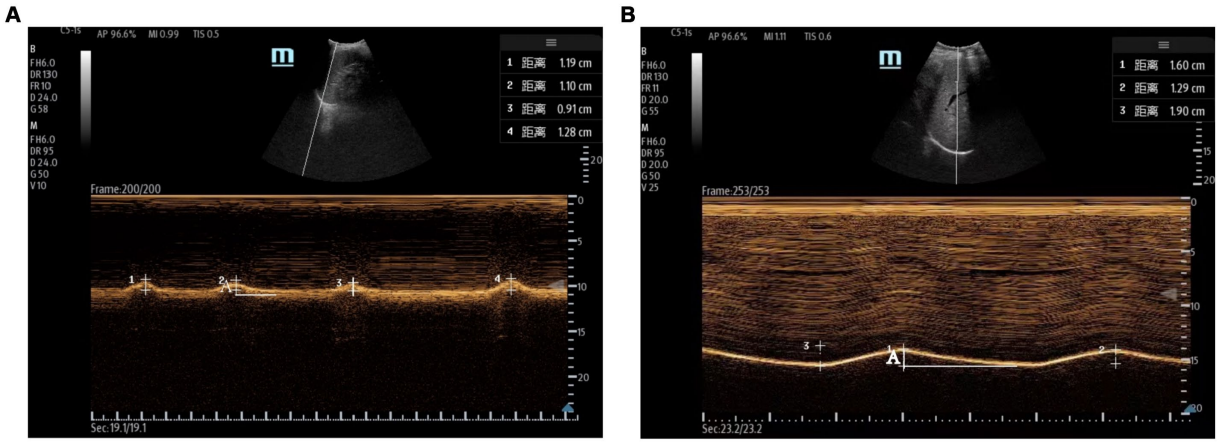

FIGURE 4
Evaluation of the diaphragm using ultrasound. **(A)** Left measurement of diaphragmatic excursion measured with the spleen as the acoustic window. **(B)** Right diaphragmatic excursion measured using the liver as an acoustic window. The total length of A is the diaphragmatic excursion for one respiratory cycle.

associated with pulmonary complications after cardiac surgery (OR: 4.29 $p=0.02$) (54), and preoperative respiratory muscle training reduces the incidence of postoperative pulmonary complications by 50% (67), this reduction occurs because the clinical presentation of DD varies from asymptomatic in mild cases to requiring prolonged mechanical ventilation or even death in severe cases (68, 69). Thus, ultrasonography can be used to detect abnormal diaphragmatic function early and prompt clinicians to intervene. Overall, there is a lack of studies on preoperative DD, nevertheless, the relevance of assessing diaphragmatic function preoperatively for postoperative prognosis is worth exploring.

Preoperative DD not only has negative effects on early clinical outcomes but also jeopardizes long-term lung function, resulting in negative outcomes such as reduced total lung volume and functional capacity, even in patients who undergo successful surgery. Therefore, patients diagnosed with DD preoperatively require individualized surgical plans and intraoperative management from surgeons and anesthesiologists, this may include preoperative monitoring of respiratory function, X-rays, and exertion spirometry assessment (70–72), these preparations can help reduce postoperative complications in patients.

Intraoperative assessment of DD

Diagnosis of intraoperative DD by ultrasound is challenging due to the position and location of surgery and the requirement for muscle relaxants in patients under general anesthesia. As a result, intraoperative studies have primarily focused on patients undergoing shoulder surgery who have received brachial plexus blocks, these blocks involve sensory numbing of the fourth and fifth cervical nerves, while Cervical 3 to Cervical 5 (C3–C5) MV blocks can cause varying degrees of diaphragmatic paralysis (73, 74). Consequently, the most common complication of brachial plexus blocks is ipsilateral diaphragmatic paralysis from phrenic nerve blocks. The reported incidence of ipsilateral hemidiaphragmatic paralysis after

TABLE 1 US assessment of diaphragmatic dysfunction in the literature.

	Cut-off values	Probe	Patient position	Measurement position	References
Diaphragm excursion (DE)	DE <10 mm	3.5–5-MHz convex ultrasound probe	Resting tidal breathing patients lying in the semirecumbent position	Right: placed between the midclavicular and anterior axillary lines Left: between the anterior and midaxillary lines	(34)
	Excursion <10 mm or negative	3.5-MHz US probe	Patients in the supine position	Right: right anterior axillary line Left: left midaxillary line	(9)
	DE <10 mm	3.5-MHz transducer	Semirecumbent position at 45°	NA	(35)
	DE <20 mm	2–5 MHz	NA	Probe aligned to the top of the diaphragm; placement not agreed upon	(18)
	Right: 2D-Mode < 10 mm or M-Mode < 11 mm Left: M-Mode < 11 mm	3.5-MHz US probe	The patient was supine with 30° head-of-bed elevation	Between the eighth and ninth ribs, on the midaxillary line	(36)
	DE <1 cm or diaphragmatic motion =0 cm	2.5–3.5-MHz phased-array transducer	Bedside with the patient in a semirecumbent position at 45°	Right: between the midclavicular and anterior axillary lines. Left: between the anterior and mid axillary lines	(37)
	DE <1 cm	2.5–3.5 MHz phased-array transducer	Bedside with the patient in a 45° semi-recumbent position	Midaxillary line	(38)
	Greater than 75% reduction in diaphragmatic excursion in the *VS* test	4-MHz curvilinear transducer	Patient in a semi-sitting position with the head elevated by approximately 30°	Right anterior axillary and midclavicular lines	(39)
	Men: DE <1 cm Women: DE <0.9 cm	2.5–3.5 MHz	Standing position	Right: between the midclavicular and anterior axillary lines. Left: between the anterior and mid axillary lines	(32)
	DE <1 cm	4-MHz linear probe	NA	NA	(40)
Diaphragm thickness (DT) Diaphragm thickness fraction (DTF)	DTF <30%	Linear probe (6–13 MHz)	Semi-recumbent position (head raised by 40°)	Right midaxillary line	(41)
	Thickness reduction >10% from baseline	7–12 MHz	NA	Midaxillary line or slightly ventral, approximately between the 8–11th ribs	(18)
	DTF <20%	7.5–10 MHz probe	Semi-recumbent position	Between the 8–10th intercostal ribs	(42)
	DT-exp <2 mm	9.0-MHz probe	NA	In line with the right intercostal space between the anteroaxillary and midaxillary lines	(43)
	DT <20%	7.5–10.0-MHz transducer	Standing position	The eight and nine intercostal spaces in the right midaxillary line	(44)
	DTF < 30%	10-MHz linear probe	NA	NA	(40)
	DTF <20%	Linear-array probe (5–10 MHz)	NA	In the right 8th or 9th intercostal space	(45)

DTF, Diaphragm thickness fraction = (inspiratory thickness − expiratory thickness)/ expiratory thickness × 100; DE, diaphragm excursion; DT-exp, Diaphragmic thickness during static inspiratory or expiratory phases, corresponding to functional residual air volume; NA, Not mentioned in the literature; VS, voluntary sniff.

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supraclavicular brachial plexus nerve block ranges from 67 to 80% (75, 76), with a much higher incidence when using the interosseous groove approach, especially if a high volume injection of 20 mL is used (74). This higher incidence could be attributed to the closer proximity of the block site to the cervical plexus, while reducing the concentration or dose of local anesthetic can lower the incidence of diaphragmatic paralysis, it comes at the expense of diminished analgesia (77). Therefore, it is important to explore how to find a critical value that achieves satisfactory pain relief while avoiding diaphragmatic paralysis. Notably, a decrease in DE of more than 75% indicates complete paralysis of the diaphragm (39), thus, utilizing ultrasound to assess diaphragmatic function in patients undergoing shoulder surgery with brachial plexus nerve block allows for early detection of the risk of diaphragmatic paralysis, which in turn enables appropriate measures to be taken, such as endotracheal intubation under general anesthesia, to prevent intraoperative respiratory distress.

Postoperative assessment of DD

In 1993, Fratacci et al. demonstrated that thoracotomy and lobectomy severely affect the active contraction of the diaphragm, leading to diaphragmatic depression (78), diaphragmatic contraction was markedly attenuated only 2 h after thoracic surgery (79). However, due to the limitations of the conditions at the time, only rough conclusions could be drawn. The definition of DD was further refined by the introduction of ultrasound in 2010, it was reported that operatively measured DE was significantly reduced compared with nonoperative measurements, highlighting the need to use ultrasound in the perioperative period to avoid errors in whole-body pulmonary function assessments (80). In an experiment of continuous diaphragm ultrasound assessment in 107 mechanically ventilated patients, 47 (44%) patients had a decrease in diaphragm thickness of more than 10%, 13 (12%) had an increase in diaphragm thickness of more than 10%, and 47 (44%) had no change in diaphragm thickness during the first week of mechanical ventilation (81). Although there was no significant difference in the results among these three groups, this study showed that ultrasonography could be used to monitor changes in the diaphragm during mechanical ventilation. Moreover, the indisputable value of dynamic diaphragm assessment through ultrasound has been further highlighted by subsequent studies.

Spadaro et al. demonstrated that the incidence of DD was higher in patients undergoing both video-assisted thoracoscopic surgery (VATS) and open thoracic surgery at a DE <10 mm (34); however, the incidence of VATS was slightly lower than that of open thoracic surgery, which is in accordance with the less invasive and better recovery characteristics of VATS. Importantly, this study demonstrated a correlation between postoperative pulmonary complications and DD at 24 h postoperatively (OR: 5.5, $p = 0.002$). In contrast, Daniel et al. compensated for Spadaro et al.'s shorter monitoring duration by using ultrasound to measure DE and DTF in patients undergoing thoracic surgery, their study included preoperative, post-extubation, and three-day postoperative assessments. They observed a significant decrease in DE following surgical interventions, both post-extubation and at the three-day mark after surgery, at 3 days, there was also a significant decrease in DTF following a similar time course. However, DE was easier to assess and more reproducible than DTF, making it more suitable for perioperative assessment of diaphragmatic dysfunction. Additionally, persistent diaphragmatic dysfunction was associated with an increased risk of pulmonary infections (OR: 9.0, $p = 0.001$), this finding is consistent with the results obtained by Spadaro et al. (82), who demonstrated that 68% of patients experienced immediate post-extubation diaphragmatic dysfunction. Spadaro et al. also reported an incidence of 68% (34) for diaphragmatic dysfunction at 3 days postoperatively, which suggests that diaphragmatic dysfunction is self-recovering but takes some time. Furthermore, the occurrence of postoperative diaphragmatic dysfunction lasting at least 3 days is related to the duration of hospitalization. However, the exact duration of postoperative diaphragmatic dysfunction has not yet been definitively determined.

In a study of cardiac surgery, Tralhão et al. extended the monitoring time to the fifth postoperative day and found that DE and DTF decreased on the first postoperative day but returned to preoperative levels by the fifth day (38). This suggests that diaphragm dysfunction occurs at a high incidence in cardiothoracic surgery. Additionally, postoperative diaphragmatic dysfunction in patients undergoing lobectomy leads to a decrease in static balance, thereby affecting the patient's daily life (83). Nevertheless, ultrasound can be used to continuously monitor diaphragm function and dynamically observe diaphragm recovery in the postoperative period, this can improve the predictive value of adverse outcomes in postoperative patients.

The incidence of DD after cardiac surgery is as high as 38% (56, 66), and persistent DD occurs in 8% of patients (57). When it occurs, it can lead to serious complications, and the incidence of postoperative DD in patients with congenital heart disease is 6.3% (84). Moury et al. found a 20% probability of a 20% reduction in the thickness of DTF at the 75% probability threshold by employing continuous ultrasonographic monitoring of DTF at pre-, mid-, and post-spontaneous breathing trial (SBT) time points (42). Despite the association between thickness reduction and prolonged hospital stay, the authors did not investigate to what extent such reductions constitute DD. Given the high incidence of thickness reduction in the postoperative period, further exploration of this question is warranted.

When DE <1 cm was used as a diagnostic criterion for DD, the incidence of bilateral DD and unilateral DD persisting until 3 days postoperatively was 36 and 12%, respectively (38). In a study by Laghlam et al., persistent DD after cardiac surgery was investigated (57), DD was defined as DE <9 mm in women and DE <10 mm in men for calm breathing, and DE <16 mm in women and DE <18 mm in men during sniffing breaths, the incidence of DD remaining on postoperative day 7 in the presence of spontaneous breathing was found to be 8% (10/122). Although there was a decrease in DE compared to patients without DD, no preoperative risk factors were identified for persistent postoperative DD.

Persistent DD can severely impair respiratory function in the postoperative period, leading to an increased frequency of pneumonia and reintubation. However, it is noteworthy that Tralhão et al. (38) reported a different trajectory, with DE returning to preoperative levels within 5 days postoperatively. Possible explanations for this discrepancy include the small sample size and relatively low age of the population studied by Tralhão et al., as well as the absence of prevalent neocoronary pneumonia at the time of their study. In addition, Pasero et al. found that 21 and 25% of patients had persistent diaphragmatic dysfunction on the right and left sides using a threshold of DTF <30% (85). Meanwhile, the incidence at DSBT was as high as 38% when DTF <20% was utilized

as the threshold (66). This discrepancy is significant compared to the 75% incidence reported by Moury et al. Several factors may explain this difference: (1) patients in the study by Moury et al. had a longer extracorporeal circulation time, which is strongly correlated with diaphragmatic dysfunction; (2) the prevalence of preoperative DD was 11% in their study, which is higher than the 7% reported by Pasero et al.; and (3) there were inconsistencies in the criteria used for diagnosing DD. Therefore, despite the relatively low incidence of persistent DD after cardiac surgery, it still has a significant impact on patient prognosis and necessitates the use of ultrasound-assisted monitoring.

Diaphragmatic ultrasound was described for the first time in the context of the recovery period after cardiac surgery. It was determined that ultrasound can be utilized as part of clinical practice for initial postoperative rehabilitation and follow-up assessment (86). While diagnostic criteria such as DE, TF, and DTF have yielded inconsistent clinical outcomes in assessing DD, DE is the preferred index for most investigators due to its high reproducibility and accuracy. Nevertheless, there is still a lack of large sample size multicenter studies to further validate the clinical applicability of each index.

Postoperative diaphragmatic dysfunction was diagnosed according to an ultrasound diaphragm thickness ratio < 1.2 in a patient who underwent gastrointestinal endoscopic surgery (65), this is a rare occurrence and suggests that flatulence after abdominal hyperextension is one of the causes of DD. Notably, cholecystectomy leads to diaphragmatic damage (87); however, this damage typically resolves within 24 h (88). However, Benhamou et al. concluded that abdominal pneumoperitoneum does not impair diaphragm function after laparoscopy (89). Nevertheless, there remains a dearth of reports elucidating the threshold for DD induced by laparoscopy and the timeframe course for the diaphragm for diaphragmatic recovery to baseline. Given the widespread adoption of laparoscopy for minimally invasive upper abdominal surgery, understanding these dynamics is crucial. Furthermore, postoperative DE decreases after upper abdominal surgery, leading to a shift from predominantly abdominal to predominantly ribcage respiration. This alteration can predispose postoperative patients to pulmonary complications such as atelectasis and hypoxemia (90). Hence, incorporating ultrasound evaluation into postoperative care protocols for upper abdominal surgery is imperative.

A study by Crothers et al. followed up lung transplant patients and found that the prevalence of diaphragmatic dysfunction decreased from 66 to 22% at 3 months postoperatively (91), this suggests that diaphragmatic dysfunction may still be present in the months following surgery; however, the prevalence decreases over time. Similar results have been observed in children (92). Ultimately, early evaluation and treatment of diaphragmatic dysfunction can improve patient prognoses.

Ultrasound assessment of diaphragmatic dysfunction in nonsurgical patients

There are few studies related to ultrasound in nonsurgical patients, such as outpatients with chronic obstructive pulmonary disease (COPD) and interstitial lung disease (ILD). However, evidence suggests that ultrasound monitoring of diaphragm function is useful in assessing a range of lung diseases (48, 93). In patients with COPD, lung hyperinflation causes the diaphragm to shift caudally, negatively affecting its function (94). The clinical presentation of COPD patients is shown in Figure 5. In the past, the assessment of patients with COPD mainly involved using the 6-min walking test and FEV1/FVC evaluation (forced expiratory volume in the first second/forced vital

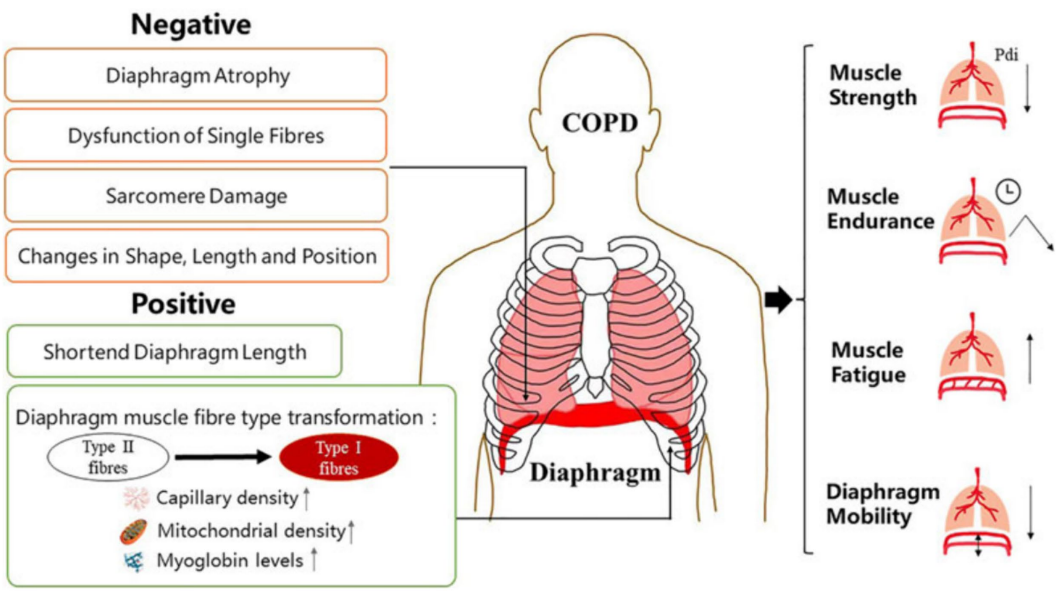

FIGURE 5
Manifestations of diaphragm dysfunction in COPD. Diaphragm dysfunction in patients with COPD is mainly manifested in structural and functional changes. Changes in diaphragm structure include both negative and positive changes. The function of diaphragm depends largely on its physiological characteristics at the structural level. COPD, chronic obstructive pulmonary disease (95).

capacity). In recent years, ultrasound has also played an important role in analyzing patients with COPD, and DE is an essential indicator of decreased exercise tolerance and dyspnea, which are related to lung function and respiratory muscle strength (96, 97). The lower normal limit value of DE in healthy subjects is 3.3 cm for men and 3.2 cm for women during deep breathing (98). This corresponds to the fact that diaphragmatic mobility is greater in men than in women. However, the diagnostic threshold for DD is significantly higher than that used in most clinical trials.

The occurrence of DD in COPD leads to a significant decrease in DTF, TF, and DE (99). Notably, ultrasound monitoring of the diaphragm, both in outpatients and hospitalized COPD patients, can effectively assess the disease status of patients (100–105). Moreover, early detection of diaphragmatic dysfunction can help in formulating relevant strategies to reduce the occurrence of adverse clinical outcomes. However, the lack of uniformity in the ultrasound criteria for diagnosing DD will result in a much higher rate of leakage and misdiagnosis. Additionally, a large number of sample sizes and experiments are needed to further validate the accuracy of the diagnostic criteria.

Bernardinello et al. conducted TF ultrasound measurements on outpatients with ILD for several months, they found that a TF <30% was the diagnostic criterion for DD. Of the 82 ILD patients followed up, 24 experienced DD, resulting in an incidence rate of 29%. Furthermore, DD was more likely to occur in patients with connective tissue disease (CTD-ILD) than in healthy subjects. In their study, TF <30% was found to be an independent predictor of moderate/severe dyspnea (OR: 3.8, $p = 0.009$ and OR: 6.3, $p = 0.021$, respectively) (41). On the other hand, idiopathic pulmonary fibrosis (IPF) patients did not exhibit similar results, this led to the conclusion that CTD-ILD, a systemic disease that may decrease muscle strength, is different from IPF, a chronic lung disease in which muscle strength is better maintained. These findings are in line with previous research (106). Additionally, CTD-ILD patients who developed DD were more likely to experience severe dyspnea. Therefore, identifying risk factors for DD in CTD-ILD patients could help prevent poor clinical outcomes. Meanwhile, another study by Santana et al. demonstrated that DE correlates with ILD severity in ILD patients, they also found that FVC% <60 is highly accurate for predicting DD (107). In clinical practice, diaphragmatic ultrasound imaging has a high sensitivity and specificity for identifying reduced DE in ILD patients with FVC% <60. By combining ultrasound with lung function indices, it becomes easier to monitor ILD patients after surgery and can also serve as a prompt for physicians to reduce the use of medications, such as corticosteroids, that may lead to myopathy.

The assessment of diaphragmatic dysfunction using ultrasound in patients with neuromuscular diseases is a critical area of study due to the essential role the diaphragm plays in respiration. Neuromuscular diseases, such as amyotrophic lateral sclerosis (ALS), Duchenne muscular dystrophy (DMD), stroke, myasthenia gravis (108), and Lambert-Eaton syndrome (46), can lead to significant diaphragmatic weakness or paralysis, severely affecting respiratory function. Consequently, in cases of acute myasthenic crisis, patients may experience acute respiratory failure requiring invasive ventilation. Transitioning to ALS, early detection poses challenges, with low survival rates primarily attributed to respiratory muscle involvement. Timely intervention is critical, as diaphragmatic ultrasound can effectively predict FVC <50% by measuring parameters such as DE (<5.5 cm) during deep breathing. This comprehensive assessment facilitates prompt intervention for respiratory failure, potentially improving patient prognosis (109).

Stroke also affects respiratory function to some extent, resulting in a notable reduction in diaphragm mobility and lung function among affected patients (110). This diminished respiratory capacity can heighten the vulnerability of stroke patients to pulmonary infections. Similarly, patients with DMD exhibit lower DE and DTF compared to healthy adults (111, 112). Although there is no cure, diaphragmatic ultrasound can provide a clinical basis for assessing diaphragmatic function. In other words, ultrasound is the preferred tool for identifying patients who may have experienced diaphragmatic dysfunction before they display clinical symptoms, enabling early intervention.

Discussion

Although ultrasound has become a commonly used tool for diagnosing diaphragmatic dysfunction in recent years due to its noninvasiveness and reusability, there is still confusion regarding the use of diagnostic indicators and criteria. Some literature suggests that diaphragmatic involvement is bilateral (66). In contrast, some studies have demonstrated that DD may be unilateral and associated with specific surgical procedures, such as lung resection (34). During quiet breathing in healthy individuals, the lower limit of normal DE is 0.9 cm and 1 cm in women and men, respectively. Meanwhile, during deep breathing, the lower limit of normal DE is 3.3 cm and 3.2 cm for women and men, respectively (98). While both lower values have been used in different articles to diagnose DD, in a randomized controlled study of patients treated with nerve blocks, DD was categorized into complete, partial, and no diaphragmatic dysfunction categories based on decreases in DE from baseline of >70%, 25–70, and < 25% (113), respectively. Overall, the metrics used to diagnose DD through ultrasound have also not been standardized and include DE (9, 34–40), DT, and DTF (18, 41–45).

By analyzing and summarizing the literature, this review found that DE is the most commonly used index. A DE measurement of <1 cm is often used to diagnose diaphragmatic dysfunction. In clinical practice, it has been observed that most normal patients have a DE between 1–2 cm, with a few exceeding 2 cm. These findings are consistent with the data obtained by Boussuges et al. regarding DE in normal subjects (32). However, there is an international consensus among experts on ultrasound diagnosis of diaphragmatic dysfunction in critically ill patients. According to this consensus, a DE <2 cm from baseline can be considered as the critical value for diagnosis of DD (18), this conclusion contradicts the findings of our review. However, it should be noted that this consensus is specifically for ICU patients, who often have additional conditions such as diaphragmatic edema, inflammation, and pulmonary atelectasis. These conditions require a greater DE to maintain normal tidal volume. Additionally, the thickness of the diaphragm is not standardized due to diaphragmatic edema and other factors, therefore, a DE <2 cm cannot be used as a diagnostic criterion for non-critical patients. In conclusion, diaphragmatic ultrasound plays an important role in clinical practice, but there is no consensus on the diagnostic criteria for non-critical patients. Currently, a DE <1 cm is the most reasonable criterion, but more

clinical studies are needed in the future to confirm and supplement this criterion. Secondly, through literature review, we also found that the incidence of diaphragmatic dysfunction caused by brachial plexus block is very high. However, brachial plexus block has now become a common anesthesia method in orthopedic surgery, which can avoid the adverse effects of general anesthesia. In the future, further research can be conducted on another approach or concentration to reduce diaphragmatic dysfunction caused by brachial plexus block. Furthermore, the use of ultrasound at the bedside is limited by the presence of poor acoustic windows in some outpatients and ICU patients (93, 114, 115) and unfavorable imaging environments in obese patients (25).

In recent years, computed tomography (CT) has emerged as a new tool for characterizing diaphragmatic function, it enables visual assessment of diaphragm density, thickness, and height (116), facilitating the prediction of reintubation rates in patients in the ICU (117). Additionally, CT allows for the static assessment of the diaphragm and observation of morphological changes over time. Looking ahead, alongside ultrasound, CT is poised to become an indispensable tool for comprehensive assessment of diaphragm function.

Conclusion

In clinical practice, ultrasound remains a commonly used tool for assessing DD, it is not only noninvasive but can also be performed at the bedside, ensuring good patient compliance. Perioperative ultrasound assessment of diaphragm function can help in preoperative preparation, intraoperative monitoring, and postoperative evaluation. It allows clinicians to promptly and accurately assess diaphragm function and guide subsequent treatment strategies. However, more clinical data are required in the future to complement and support this review, with the ultimate goal of reaching a consensus on ultrasound assessment in non-critical patients.

Author contributions

X-YY: Writing – original draft. H-ML: Writing – review & editing. B-WS: Writing – review & editing. Y-YZ: Writing – review & editing, Investigation. J-GF: Writing – original draft, Resources. JJ: Writing – review & editing, Methodology. LL: Writing – review & editing, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

1. Mccool FD, Manzoor K, Minami T. Disorders of the diaphragm. *Clin Chest Med*. (2018) 39:345–60. doi: 10.1016/j.ccm.2018.01.012

2. Mead J, Loring SH. Analysis of volume displacement and length changes of the diaphragm during breathing. *J Appl Physiol Respir Environ Exerc Physiol*. (1982) 53:750–5. doi: 10.1152/jappl.1982.53.3.750

3. Ishida H, Kobara K, Osaka H, Suehiro T, Ito T, Kurozumi C, et al. Correlation between peak expiratory flow and abdominal muscle thickness. *J Phys Ther Sci*. (2014) 26:1791–3. doi: 10.1589/jpts.26.1791

4. Demoule A, Jung B, Prodanovic H, Molinari N, Chanques G, Coirault C, et al. Diaphragm dysfunction on admission to the intensive care unit. Prevalence, risk factors, and prognostic impact-a prospective study. *Am J Respir Crit Care Med*. (2013) 188:213–9. doi: 10.1164/rccm.201209-1668OC

5. Demoule A, Molinari N, Jung B, Prodanovic H, Chanques G, Matecki S, et al. Patterns of diaphragm function in critically ill patients receiving prolonged mechanical ventilation: a prospective longitudinal study. *Ann Intensive Care*. (2016) 6:75. doi: 10.1186/s13613-016-0179-8

6. Dres M, Dubé BP, Mayaux J, Delemazure J, Reuter D, Brochard L, et al. Coexistence and impact of limb muscle and diaphragm weakness at time of liberation from mechanical ventilation in medical intensive care unit patients. *Am J Respir Crit Care Med*. (2017) 195:57–66. doi: 10.1164/rccm.201602-0367OC

7. Dubé BP, Dres M, Mayaux J, Demiri S, Similowski T, Demoule A. Ultrasound evaluation of diaphragm function in mechanically ventilated patients: comparison to phrenic stimulation and prognostic implications. *Thorax*. (2017) 72:811–8. doi: 10.1136/thoraxjnl-2016-209459

8. Jung B, Moury PH, Mahul M, De Jong A, Galia F, Prades A, et al. Diaphragmatic dysfunction in patients with ICU-acquired weakness and its impact on extubation failure. *Intensive Care Med*. (2016) 42:853–61. doi: 10.1007/s00134-015-4125-2

9. Kim WY, Suh HJ, Hong SB, Koh Y, Lim CM. Diaphragm dysfunction assessed by ultrasonography: influence on weaning from mechanical ventilation. *Crit Care Med*. (2011) 39:2627–30. doi: 10.1097/CCM.0b013e3182266408

10. Goligher EC, Dres M, Fan E, Rubenfeld GD, Scales DC, Herridge MS, et al. Mechanical ventilation-induced diaphragm atrophy strongly impacts clinical outcomes. *Am J Respir Crit Care Med*. (2018) 197:204–13. doi: 10.1164/rccm.201703-0536OC

11. Laghi F, Tobin MJ. Disorders of the respiratory muscles. *Am J Respir Crit Care Med*. (2003) 168:10–48. doi: 10.1164/rccm.2206020

12. Tobin MJ, Laghi F, Jubran A. Ventilatory failure, ventilator support, and ventilator weaning. *Compr Physiol*. (2012) 2:2871–921. doi: 10.1002/cphy.c110030

13. Béduneau G, Pham T, Schortgen F, Piquilloud L, Zogheib E, Jonas M, et al. Epidemiology of weaning outcome according to a new definition. The wind study. *Am J Respir Crit Care Med*. (2017) 195:772–83. doi: 10.1164/rccm.201602-0320OC

14. Polkey MI, Green M, Moxham J. Measurement of respiratory muscle strength. *Thorax*. (1995) 50:1131–5. doi: 10.1136/thx.50.11.1131

15. Durand MC, Porcher R, Orlikowski D, Aboab J, Devaux C, Clair B, et al. Clinical and electrophysiological predictors of respiratory failure in Guillain-Barré syndrome: a prospective study. *Lancet Neurol*. (2006) 5:1021–8. doi: 10.1016/S1474-4422(06)70603-2

16. Le Pimpec-Barthes F, Hernigou A, Mazzella A, Legras A, Rivera C, Bouacida I, et al. Dynamic magnetic resonance imaging in unilateral diaphragm eventration:

knowledge improvement before and after plication. *J Thorac Dis*. (2019) 11:3467–75. doi: 10.21037/jtd.2019.07.79

17. Semplicini C, De Antonio M, Taouagh N, Béhin A, Bouhour F, Echaniz-Laguna A, et al. Long-term benefit of enzyme replacement therapy with Alglucosidase alfa in adults with Pompe disease: prospective analysis from the French Pompe registry. *J Inherit Metab Dis*. (2020) 43:1219–31. doi: 10.1002/jimd.12272

18. Haaksma ME, Smit JM, Boussuges A, Demoule A, Dres M, Ferrari G, et al. Expert consensus on diaphragm ultrasonography in the critically ill (exodus): a Delphi consensus statement on the measurement of diaphragm ultrasound-derived parameters in a critical care setting. *Crit Care*. (2022) 26:99. doi: 10.1186/s13054-022-03975-5

19. Dres M, Goligher EC, Heunks LMA, Brochard LJ. Critical illness-associated diaphragm weakness. *Intensive Care Med*. (2017) 43:1441–52. doi: 10.1007/s00134-017-4928-4

20. Mccool FD, Tzelepis GE. Dysfunction of the diaphragm. *N Engl J Med*. (2012) 366:932–42. doi: 10.1056/NEJMra1007236

21. Zambon M, Greco M, Bocchino S, Cabrini L, Beccaria PF, Zangrillo A. Assessment of diaphragmatic dysfunction in the critically ill patient with ultrasound: a systematic review. *Intensive Care Med*. (2017) 43:29–38. doi: 10.1007/s00134-016-4524-z

22. Boon AJ, Harper CJ, Ghahfarokhi LS, Strommen JA, Watson JC, Sorenson EJ. Two-dimensional ultrasound imaging of the diaphragm: quantitative values in Normal subjects. *Muscle Nerve*. (2013) 47:884–9. doi: 10.1002/mus.23702

23. Cohn D, Benditt JO, Eveloff S, Mccool FD. Diaphragm thickening during inspiration. *J Appl Physiol*. (1997) 1985:291–6. doi: 10.1152/jappl.1997.83.1.291

24. Kantarci F, Mihmanli I, Demirel MK, Harmanci K, Akman C, Aydogan F, et al. Normal diaphragmatic motion and the effects of body composition: determination with M-mode sonography. *J Ultrasound Med*. (2004) 23:255–60. doi: 10.7863/jum.2004.23.2.255

25. Ueki J, De Bruin PF, Pride NB. In vivo assessment of diaphragm contraction by ultrasound in Normal subjects. *Thorax*. (1995) 50:1157–61. doi: 10.1136/thx.50.11.1157

26. Wait JL, Nahormek PA, Yost WT, Rochester DP. Diaphragmatic thickness-lung volume relationship in vivo. *J Appl Physiol*. (1989) 1985:1560–8. doi: 10.1152/jappl.1989.67.4.1560

27. Akiyama N, Ishikawa S, Takeuchi T. Ultrasonographic evaluation of the influence of different postures on diaphragmatic motion in mechanically ventilated patients. *Eur J Ultrasound*. (2000) 11:205–11. doi: 10.1016/S0929-8266(00)00089-6

28. Laghi FA Jr, Saad M, Shaikh H. Ultrasound and non-ultrasound imaging techniques in the assessment of diaphragmatic dysfunction. *BMC Pulm Med*. (2021) 21:85. doi: 10.1186/s12890-021-01441-6

29. Matamis D, Soilemezi E, Tsagourias M, Akoumianaki E, Dimassi S, Boroli F, et al. Sonographic evaluation of the diaphragm in critically ill patients. Technique and clinical applications. *Intensive Care Med*. (2013) 39:801–10. doi: 10.1007/s00134-013-2823-1

30. Yu X, Jiang HY, Zhang CX, Jin ZH, Gao L, Wang RD, et al. The role of the diaphragm in postural stability and visceral function in Parkinson's disease. *Front Aging Neurosci*. (2021) 13:785020. doi: 10.3389/fnagi.2021.785020

31. Ye X, Liu Z, Ma Y, Song Y, Hu L, Luo J, et al. A novel normalized cross-correlation speckle-tracking ultrasound algorithm for the evaluation of diaphragm deformation. *Front Med (Lausanne)*. (2021) 8:612933. doi: 10.3389/fmed.2021.612933

32. Boussuges A, Gole Y, Blanc P. Diaphragmatic motion studied by M-mode ultrasonography: methods, reproducibility, and normal values. *Chest*. (2009) 135:391–400. doi: 10.1378/chest.08-1541

33. Gethin-Jones TL, Noble VE, Morse CR. Quantification of diaphragm function using ultrasound: evaluation of a novel technique. *Ultrasound Med Biol*. (2010) 36:1965–9. doi: 10.1016/j.ultrasmedbio.2010.08.003

34. Spadaro S, Grasso S, Dres M, Fogagnolo A, Dalla Corte F, Tamburini N, et al. Point of care ultrasound to identify diaphragmatic dysfunction after thoracic surgery. *Anesthesiology*. (2019) 131:266–78. doi: 10.1097/ALN.0000000000002774

35. Valette X, Seguin A, Daubin C, Brunet J, Sauneuf B, Terzi N, et al. Diaphragmatic dysfunction at admission in intensive care unit: the value of diaphragmatic ultrasonography. *Intensive Care Med*. (2015) 41:557–9. doi: 10.1007/s00134-014-3636-6

36. Mariani LF, Bedel J, Gros A, Lerolle N, Milojevic K, Laurent V, et al. Ultrasonography for screening and follow-up of diaphragmatic dysfunction in the ICU: a pilot study. *J Intensive Care Med*. (2016) 31:338–43. doi: 10.1177/0885066615583639

37. Pasero D, Koeltz A, Placido R, Fontes Lima M, Haun O, Rienzo M, et al. Improving ultrasonic measurement of diaphragmatic excursion after cardiac surgery using the anatomical M-mode: a randomized crossover study. *Intensive Care Med*. (2015) 41:650–6. doi: 10.1007/s00134-014-3625-9

38. Tralhão A, Cavaleiro P, Arrigo M, Lopes JP, Lebrun M, Rivas-Lasarte M, et al. Early changes in diaphragmatic function evaluated using ultrasound in cardiac surgery patients: a cohort study. *J Clin Monit Comput*. (2020) 34:559–66. doi: 10.1007/s10877-019-00350-8

39. Petrar SD, Seltenrich ME, Head SJ, Schwarz SK. Hemidiaphragmatic paralysis following ultrasound-guided supraclavicular versus infraclavicular brachial plexus blockade: a randomized clinical trial. *Reg Anesth Pain Med*. (2015) 40:133–8. doi: 10.1097/AAP.0000000000000215

40. Vivier E, Muller M, Putegnat JB, Steyer J, Barrau S, Boissier F, et al. Inability of diaphragm ultrasound to predict extubation failure: a multicenter study. *Chest*. (2019) 155:1131–9. doi: 10.1016/j.chest.2019.03.004

41. Bernardinello N, Cocconcelli E, Boscolo A, Castelli G, Sella N, Giraudo C, et al. Prevalence of diaphragm dysfunction in patients with interstitial lung disease (Ild): the role of diaphragmatic ultrasound. *Respir Med*. (2023) 216:107293. doi: 10.1016/j.rmed.2023.107293

42. Moury PH, Cuisinier A, Durand M, Bosson JL, Chavanon O, Payen JF, et al. Diaphragm thickening in cardiac surgery: a perioperative prospective ultrasound study. *Ann Intensive Care*. (2019) 9:50. doi: 10.1186/s13613-019-0521-z

43. Miyagi M, Kinugasa Y, Sota T, Yamada K, Ishisugi T, Hirai M, et al. Diaphragm muscle dysfunction in patients with heart failure. *J Card Fail*. (2018) 24:209–16. doi: 10.1016/j.cardfail.2017.12.004

44. Gottesman E, Mccool FD. Ultrasound evaluation of the paralyzed diaphragm. *Am J Respir Crit Care Med*. (1997) 155:1570–4. doi: 10.1164/ajrccm.155.5.9154859

45. Hadda V, Pahuja S, Mittal S, Madan K, Khan MA, Mohan A, et al. Effects of neurally adjusted ventilation assist (Nava) and conventional modes of mechanical ventilation on diaphragm functions: a randomized controlled trial. *Heart Lung*. (2022) 53:36–41. doi: 10.1016/j.hrtlng.2022.01.016

46. Benditt JO, Boitano LJ. Pulmonary issues in patients with chronic neuromuscular disease. *Am J Respir Crit Care Med*. (2013) 187:1046–55. doi: 10.1164/rccm.201210-1804CI

47. Fayssoil A, Nguyen LS, Ogna A, Stojkovic T, Meng P, Mompoint D, et al. Diaphragm sniff ultrasound: Normal values, relationship with sniff nasal pressure and accuracy for predicting respiratory involvement in patients with neuromuscular disorders. *PLoS One*. (2019) 14:E0214288. doi: 10.1371/journal.pone.0214288

48. Umbrello M, Formenti P, Longhi D, Galimberti A, Piva I, Pezzi A, et al. Diaphragm ultrasound as Indicator of respiratory effort in critically ill patients undergoing assisted mechanical ventilation: a pilot clinical study. *Crit Care*. (2015) 19:161. doi: 10.1186/s13054-015-0894-9

49. Dinino E, Gartman EJ, Sethi JM, Mccool FD. Diaphragm ultrasound as a predictor of successful Extubation from mechanical ventilation. *Thorax*. (2014) 69:423–7. doi: 10.1136/thoraxjnl-2013-204111

50. Messina A, Robba C, Bertuetti R, Biasucci D, Corradi F, Mojoli F, et al. Head to toe ultrasound: a narrative review of Experts' recommendations of methodological approaches. *J Anesth Analg Crit Care*. (2022) 2:44. doi: 10.1186/s44158-022-00072-5

51. Cammarota G, Sguazzotti I, Zanoni M, Messina A, Colombo D, Vignazia GL, et al. Diaphragmatic ultrasound assessment in subjects with acute hypercapnic respiratory failure admitted to the emergency department. *Respir Care*. (2019) 64:1469–77. doi: 10.4187/respcare.06803

52. Cammarota G, Esposito T, Azzolina D, Cosentini R, Menzella F, Aliberti S, et al. Noninvasive respiratory support outside the intensive care unit for acute respiratory failure related to Coronavirus-19 disease: a systematic review and meta-analysis. *Crit Care*. (2021) 25:268. doi: 10.1186/s13054-021-03697-0

53. Lang J, Liu Y, Zhang Y, Huang Y, Yi J. Peri-operative diaphragm ultrasound as a new method of recognizing post-operative residual curarization. *BMC Anesthesiol*. (2021) 21:287. doi: 10.1186/s12871-021-01506-3

54. Cavayas YA, Eljaiek R, Rodrigue É, Lamarche Y, Girard M, Wang HT, et al. Preoperative diaphragm function is associated with postoperative pulmonary complications after cardiac surgery. *Crit Care Med*. (2019) 47:E966–74. doi: 10.1097/CCM.0000000000004027

55. Kim SH, Na S, Choi JS, Na SH, Shin S, Koh SO. An evaluation of diaphragmatic movement by M-mode sonography as a predictor of pulmonary dysfunction after upper abdominal surgery. *Anesth Analg*. (2010) 110:1349–54. doi: 10.1213/ANE.0b013e3181d5e4d8

56. Laghlam D, Lê MP, Srour A, Monsonego R, Estagnasié P, Brusset A, et al. Diaphragm dysfunction after cardiac surgery: reappraisal. *J Cardiothorac Vasc Anesth*. (2021) 35:3241–7. doi: 10.1053/j.jvca.2021.02.023

57. Laghlam D, Naudin C, Srour A, Monsonego R, Malvy J, Rahoual G, et al. Persistent diaphragm dysfunction after cardiac surgery is associated with adverse respiratory outcomes: a prospective observational ultrasound study. *Can J Anaesth*. (2023) 70:228–36. doi: 10.1007/s12630-022-02360-8

58. Simonneau G, Vivien A, Sartene R, Kunstlinger F, Samii K, Noviant Y, et al. Diaphragm dysfunction induced by upper abdominal surgery. Role of postoperative pain. *Am Rev Respir Dis*. (1983) 128:899–903. doi: 10.1164/arrd.1983.128.5.899

59. Guzel S, Umay E, Gundogdu I, Bahtiyarca ZT, Cankurtaran D. Effects of diaphragm thickness on rehabilitation outcomes in post-ICU patients with spinal cord and brain injury. *Eur J Trauma Emerg Surg*. (2022) 48:559–65. doi: 10.1007/s00068-020-01426-w

60. Kokatnur L, Rudrappa M. Diaphragmatic palsy. *Diseases*. (2018) 6:16. doi: 10.3390/diseases6010016

61. Gaissert H, Wilcox SR. Diaphragmatic dysfunction after thoracic operations. *Thorac Cardiovasc Surg*. (2016) 64:621–30. doi: 10.1055/s-0036-1595816

62. Ricoy J, Rodríguez-Núñez N, Álvarez-Dobaño JM, Toubes ME, Riveiro V, Valdés L. Diaphragmatic dysfunction. *Pulmonology*. (2019) 25:223–35. doi: 10.1016/j.pulmoe.2018.10.008

63. Supinski GS, Morris PE, Dhar S, Callahan LA. Diaphragm dysfunction in critical illness. *Chest*. (2018) 153:1040–51. doi: 10.1016/j.chest.2017.08.1157

64. Huh S, Cho WH, Kim D, Son BS, Yeo HJ. Clinical impact of preoperative diaphragm dysfunction on early outcomes and ventilation function in lung transplant: a single-center retrospective study. *J Intensive Care*. (2022) 10:23. doi: 10.1186/s40560-022-00614-7

65. Hazama K, Toda Y, Nakatsuka H, Fujita Y. Ultrasonographic diagnosis for dysfunction of the diaphragm after iatrogenic tension pneumoperitoneum by a gastrointestinal endoscopic procedure: a case report. *A A Pract*. (2019) 12:33–6. doi: 10.1213/XAA.0000000000000830

66. Bruni A, Garofalo E, Pasin L, Serraino GF, Cammarota G, Longhini F, et al. Diaphragmatic dysfunction after elective cardiac surgery: a prospective observational study. *J Cardiothorac Vasc Anesth*. (2020) 34:3336–44. doi: 10.1053/j.jvca.2020.06.038

67. Hulzebos EH, Helders PJ, Favié NJ, De Bie RA, Brutel De La Riviere A, Van Meeteren NL. Preoperative intensive inspiratory muscle training to prevent postoperative pulmonary complications in high-risk patients undergoing Cabg surgery: a randomized clinical trial. *JAMA*. (2006) 296:1851–7. doi: 10.1001/jama.296.15.1851

68. Aguirre VJ, Sinha P, Zimmet A, Lee GA, Kwa L, Rosenfeldt F. Phrenic nerve injury during cardiac surgery: mechanisms, management and prevention. *Heart Lung Circ*. (2013) 22:895–902. doi: 10.1016/j.hlc.2013.06.010

69. Stevenson JG. Effect of unilateral diaphragm paralysis on branch pulmonary artery flow. *J Am Soc Echocardiogr*. (2002) 15:1132–9. doi: 10.1067/mje.2002.123256

70. Birnkrant DJ, Panitch HB, Benditt JO, Boitano LJ, Carter ER, Cwik VA, et al. American college of chest physicians consensus statement on the respiratory and related management of patients with Duchenne muscular dystrophy undergoing anesthesia or sedation. *Chest*. (2007) 132:1977–86. doi: 10.1378/chest.07-0458

71. Blichfeldt-Lauridsen L, Hansen BD. Anesthesia and myasthenia gravis. *Acta Anaesthesiol Scand*. (2012) 56:17–22. doi: 10.1111/j.1399-6576.2011.02558.x

72. Van Den Bersselaar LR, Heytens L, Silva HCA, Reimann J, Tasca G, Díaz-Cambronero Ó, et al. European neuromuscular Centre consensus statement on anaesthesia in patients with neuromuscular disorders. *Eur J Neurol*. (2022) 29:3486–507. doi: 10.1111/ene.15526

73. Haji K, Royse A, Green C, Botha J, Canty D, Royse C. Interpreting diaphragmatic movement with bedside imaging, review article. *J Crit Care*. (2016) 34:56–65. doi: 10.1016/j.jcrc.2016.03.006

74. Urmey WF, Talts KH, Sharrock NE. One hundred percent incidence of hemidiaphragmatic paresis associated with interscalene brachial plexus anesthesia as diagnosed by ultrasonography. *Anesth Analg*. (1991) 72:498–503. doi: 10.1213/00000539-199104000-00014

75. Knoblanche GE. The incidence and aetiology of phrenic nerve blockade associated with supraclavicular brachial plexus block. *Anaesth Intensive Care*. (1979) 7:346–9. doi: 10.1177/0310057X7900700406

76. Shaw WM. Paralysis of the phrenic nerve during brachial plexus anesthesia. *Anesthesiology*. (1949) 10:627–8. doi: 10.1097/00000542-194909000-00015

77. Wong AK, Keeney LG, Chen L, Williams R, Liu J, Elkassabany NM. Effect of local anesthetic concentration (0.2% vs 0.1% Ropivacaine) on pulmonary function, and analgesia after ultrasound-guided interscalene brachial plexus block: a randomized controlled study. *Pain Med*. (2016) 17:2397–403. doi: 10.1093/pm/pnw057

78. Fratacci MD, Kimball WR, Wain JC, Kacmarek RM, Polaner DM, Zapol WM. Diaphragmatic shortening after thoracic surgery in humans. Effects of mechanical ventilation and thoracic epidural anesthesia. *Anesthesiology*. (1993) 79:654–65. doi: 10.1097/00000542-199310000-00005

79. Welvaart WN, Paul MA, Stienen GJ, Van Hees HW, Loer SA, Bouwman R, et al. Selective diaphragm muscle weakness after contractile inactivity during thoracic surgery. *Ann Surg*. (2011) 254:1044–9. doi: 10.1097/SLA.0b013e318232e75b

80. Fedullo AJ, Lerner RM, Gibson J, Shayne DS. Sonographic measurement of diaphragmatic motion after coronary artery bypass surgery. *Chest*. (1992) 102:1683–6. doi: 10.1378/chest.102.6.1683

81. Goligher EC, Fan E, Herridge MS, Murray A, Vorona S, Brace D, et al. Evolution of diaphragm thickness during mechanical ventilation. Impact of inspiratory effort. *Am J Respir Crit Care Med*. (2015) 192:1080–8. doi: 10.1164/rccm.201503-0620OC

82. Daniel M, Lang E, Huynh TM, Martin J, Brebion M, Guessous K, et al. Prevalence and time-course of diaphragmatic dysfunction following lung resection: a repeated ultrasonic assessment. *Anaesth Crit Care Pain Med*. (2022) 41:101024. doi: 10.1016/j.accpm.2022.101024

83. Kocjan J, Gzik-Zroska B, Nowakowska-Lipiec K, Burkacki M, Suchoń S, Michnik R, et al. Thoracic surgery may alter body static balance via diaphragm dysfunction. *PLoS One*. (2022) 17:E0273641. doi: 10.1371/journal.pone.0273641

84. Öztürk E, Tanıdır İC, Yıldız O, Yükçü B, Ergün S, Haydın S, et al. Ultrasonographic postoperative evaluation of diaphragm function of patients with congenital heart defects. *Turk Gogus Kalp Damar Cerrahisi Derg*. (2020) 28:70–5. doi: 10.5606/tgkdc.dergisi.2020.18458

85. Pasero D, Costamagna A, Marchisio A, Pivetta E, Giunta M, Fanelli V, et al. Diaphragmatic dysfunction following cardiac surgery: observational study. *Eur J Anaesthesiol*. (2019) 36:612–3. doi: 10.1097/EJA.0000000000000969

86. Maranta F, Cianfanelli L, Rizza V, Cartella I, Pistoni A, Avitabile M, et al. Diaphragm dysfunction after cardiac surgery: insights from ultrasound imaging during cardiac rehabilitation. *Ultrasound Med Biol*. (2022) 48:1179–89. doi: 10.1016/j.ultrasmedbio.2022.02.011

87. Ayoub J, Cohendy R, Prioux J, Ahmaidi S, Bourgeois JM, Dauzat M, et al. Diaphragm movement before and after cholecystectomy: a sonographic study. *Anesth Analg*. (2001) 92:755–61. doi: 10.1097/00000539-200103000-00038

88. Sharma RR, Axelsson H, Oberg A, Jansson E, Clergue F, Johansson G, et al. Diaphragmatic activity after laparoscopic cholecystectomy. *Anesthesiology*. (1999) 91:406–13. doi: 10.1097/00000542-199908000-00014

89. Benhamou D, Simonneau G, Poynard T, Goldman M, Chaput JC, Duroux P. Diaphragm function is not impaired by pneumoperitoneum after laparoscopy. *Arch Surg*. (1993) 128:430–2. doi: 10.1001/archsurg.1993.01420160068010

90. Ford GT, Whitelaw WA, Rosenal TW, Cruse PJ, Guenter CA. Diaphragm function after upper abdominal surgery in humans. *Am Rev Respir Dis*. (1983) 127:431–6. doi: 10.1164/arrd.1983.127.4.431

91. Crothers E, Kennedy DS, Emmanuel S, Molan N, Scott S, Rogers K, et al. Incidence of early diaphragmatic dysfunction after lung transplantation: results of a prospective observational study. *Clin Transpl*. (2021) 35:E14409. doi: 10.1111/ctr.14409

92. Manczur TI, Greenough A, Rafferty GF, Dimitriou G, Baker AJ, Mieli-Vergani G, et al. Diaphragmatic dysfunction after pediatric orthotopic liver transplantation. *Transplantation*. (2002) 73:228–32. doi: 10.1097/00007890-200201270-00013

93. Goligher EC, Laghi F, Detsky ME, Farias P, Murray A, Brace D, et al. Measuring diaphragm thickness with ultrasound in mechanically ventilated patients: feasibility, reproducibility and validity. *Intensive Care Med*. (2015) 41:642–9. doi: 10.1007/s00134-015-3687-3

94. De Troyer A. Effect of hyperinflation on the diaphragm. *Eur Respir J*. (1997) 10:708–13. doi: 10.1183/09031936.97.10030708

95. Cao Y, Li P, Wang Y, Liu X, Wu W. Diaphragm dysfunction and rehabilitation strategy in patients with chronic obstructive pulmonary disease. *Front Physiol*. (2022) 13:872277. doi: 10.3389/fphys.2022.872277

96. Paulin E, Yamaguti WP, Chammas MC, Shibao S, Stelmach R, Cukier A, et al. Influence of diaphragmatic mobility on exercise tolerance and dyspnea in patients with COPD. *Respir Med*. (2007) 101:2113–8. doi: 10.1016/j.rmed.2007.05.024

97. Rocha FR, Brüggemann AK, Francisco DS, Medeiros CS, Rosal D, Paulin E. Diaphragmatic mobility: relationship with lung function, respiratory muscle strength, dyspnea, and physical activity in daily life in patients with COPD. *J Bras Pneumol*. (2017) 43:32–7. doi: 10.1590/s1806-37562016000000097

98. Boussuges A, Finance J, Chaumet G, Brégeon F. Diaphragmatic motion recorded by M-mode ultrasonography: limits of normality. *ERJ Open Res*. (2021) 7:00714–2020. doi: 10.1183/23120541.00714-2020

99. Yalçin B, Sekmenli N, Baktik B, Bekçi TT. Evaluation of diaphragm thickness and function with ultrasound technique and comparison with spirometry in stable chronic obstructive pulmonary disease. *Tuberk Toraks*. (2022) 70:76–84. doi: 10.5578/tt.20229909

100. Epelman M, Navarro OM, Daneman A, Miller SF. M-mode sonography of diaphragmatic motion: description of technique and experience in 278 pediatric patients. *Pediatr Radiol*. (2005) 35:661–7. doi: 10.1007/s00247-005-1433-7

101. Lim SY, Lim G, Lee YJ, Cho YJ, Park JS, Yoon HI, et al. Ultrasound assessment of diaphragmatic function during acute exacerbation of chronic obstructive pulmonary disease: a pilot study. *Int J Chron Obstruct Pulmon Dis*. (2019) 14:2479–84. doi: 10.2147/COPD.S214716

102. Ogan N, Aydemir Y, Evrin T, Ataç GK, Baha A, Katipoğlu B, et al. Diaphragmatic thickness in chronic obstructive lung disease and relationship with clinical severity parameters. *Turk J Med Sci*. (2019) 49:1073–8. doi: 10.3906/sag-1901-164

103. Okura K, Iwakura M, Shibata K, Kawagoshi A, Sugawara K, Takahashi H, et al. Diaphragm thickening assessed by ultrasonography is lower than healthy adults in patients with chronic obstructive pulmonary disease. *Clin Respir J*. (2020) 14:521–6. doi: 10.1111/crj.13161

104. Qaiser M, Khan N, Jain A. Ultrasonographic assessment of diaphragmatic excursion and its correlation with spirometry in chronic obstructive pulmonary disease patients. *Int J Appl Basic Med Res*. (2020) 10:256–9. doi: 10.4103/ijabmr.IJABMR_192_20

105. Shiraishi M, Higashimoto Y, Sugiya R, Mizusawa H, Takeda Y, Fujita S, et al. Diaphragmatic excursion correlates with exercise capacity and dynamic hyperinflation in COPD patients. *ERJ Open Res*. (2020) 6:00589–2020. doi: 10.1183/23120541.00589-2020

106. Boccatonda A, Decorato V, Cocco G, Marinari S, Schiavone C. Ultrasound evaluation of diaphragmatic mobility in patients with idiopathic lung fibrosis: a pilot study. *Multidiscip Respir Med*. (2019) 14:1. doi: 10.1186/s40248-018-0159-y

107. Santana PV, Prina E, Albuquerque AL, Carvalho CR, Caruso P. Identifying decreased diaphragmatic mobility and diaphragm thickening in interstitial lung disease: the utility of ultrasound imaging. *J Bras Pneumol*. (2016) 42:88–94. doi: 10.1590/S1806-37562015000000266

108. Witoonpanich R, Vichayanrat E, Tantisiriwit K, Wongtanate M, Sucharitchan N, Oranrigsupak P, et al. Survival analysis for respiratory failure in patients with food-borne botulism. *Clin Toxicol (Phila)*. (2010) 48:177–83. doi: 10.3109/15563651003596113

109. Carrié C, Bonnardel E, Vally R, Revel P, Marthan R, Marthan R. Vital capacity impairment due to neuromuscular disease and its correlation with diaphragmatic ultrasound: a preliminary study. *Ultrasound Med Biol*. (2016) 42:143–9. doi: 10.1016/j.ultrasmedbio.2015.09.020

110. Jung KJ, Park JY, Hwang DW, Kim JH, Kim JH. Ultrasonographic diaphragmatic motion analysis and its correlation with pulmonary function in hemiplegic stroke patients. *Ann Rehabil Med*. (2014) 38:29–37. doi: 10.5535/arm.2014.38.1.29

111. Fayssoil A, Chaffaut C, Ogna A, Stojkovic T, Lamothe L, Mompoint D, et al. Echographic assessment of diaphragmatic function in Duchenne muscular dystrophy from childhood to adulthood. *J Neuromuscul Dis*. (2019) 6:55–64. doi: 10.3233/JND-180326

112. Laviola M, Priori R, D'angelo MG, Aliverti A. Assessment of diaphragmatic thickness by ultrasonography in Duchenne muscular dystrophy (DMD) patients. *PLoS One*. (2018) 13:E0200582. doi: 10.1371/journal.pone.0200582

113. Kim DH, Lin Y, Beathe JC, Liu J, Oxendine JA, Haskins SC, et al. Superior trunk block: a phrenic-sparing alternative to the interscalene block: a randomized controlled trial. *Anesthesiology*. (2019) 131:521–33. doi: 10.1097/ALN.0000000000002841

114. Oppersma E, Hatam N, Doorduin J, Van Der Hoeven JG, Marx G, Goetzenich A, et al. Functional assessment of the diaphragm by speckle tracking ultrasound during inspiratory loading. *J Appl Physiol*. (2017) 1985:1063–70. doi: 10.1152/japplphysiol.00095.2017

115. Vivier E, Mekontso Dessap A, Dimassi S, Vargas F, Lyazidi A, Thille AW, et al. Diaphragm ultrasonography to estimate the work of breathing during non-invasive ventilation. *Intensive Care Med*. (2012) 38:796–803. doi: 10.1007/s00134-012-2547-7

116. Donovan AA, Johnston G, Moore M, Jensen D, Benedetti A, Coxson HO, et al. Diaphragm morphology assessed by computed tomography in chronic obstructive pulmonary disease. *Ann Am Thorac Soc*. (2021) 18:955–62. doi: 10.1513/AnnalsATS.202007-865OC

117. Parlak S, Beşler MS, Gökhan MB. Association of diaphragm thickness and density measured on chest CT with disease severity in Covid-19 patients. *Am J Emerg Med*. (2022) 61:29–33. doi: 10.1016/j.ajem.2022.08.029

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Mortality and its associated factors among mechanically ventilated adult patients in the intensive care units of referral hospitals in Northwest Amhara, Ethiopia, 2023

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Background: Worldwide, nearly half of the patients admitted to intensive care units require ventilatory support. Despite advances in intensive care unit patient management and mechanical ventilator utilization, the odds of mortality among mechanically ventilated patients are higher in resource-limited settings. Little is known about the mortality of patients on mechanical ventilation outside the capital of Ethiopia. This study aimed to assess mortality and its associated factors among mechanically ventilated adult patients in intensive care units.

Method: An institutional-based cross-sectional study was conducted on mechanically ventilated patients in intensive care units from 1 February 2020 to 1 March 2023. A simple random sampling technique was used to select 434 patients' charts. A data extraction tool designed on the Kobo toolbox, a smartphone data collection platform, was used to collect the data. The data were exported into Microsoft Excel 2019 and then into Stata 17 for data management and analysis. Descriptive statistics were used to summarize the characteristics of the study participants. A bivariable logistic regression was conducted, and variables with $p \leq 0.20$ were recruited for multivariable analysis. Statistical significance was declared at $p < 0.05$, and the strength of associations was summarized using an adjusted odds ratio with 95% confidence intervals.

Result: A total of 404 charts of mechanically ventilated patients were included, with a completeness rate of 93.1%. The overall proportion of mortality was 62.87%, with a 95% CI of (58.16–67.58). In the multivariable logistic regression, age 41–70 years (AOR: 4.28, 95% CI: 1.89–9.62), sepsis (AOR: 2.43, 95% CI: 1.08–5.46), reintubation (AOR: 2.76, 95% CI: 1.06–7.21), and sedation use (AOR: 0.41, 95% CI: 0.18–0.98) were found to be significant factors associated with the mortality of mechanically ventilated patients in the intensive care unit.

Conclusion: The magnitude of mortality among mechanically ventilated patients was high. Factors associated with increased odds of death were advanced age, sepsis, and reintubation. However, sedation use was a factor associated with decreased mortality. Healthcare professionals in intensive care units should

pay special attention to patients with sepsis, those requiring reintubation, those undergoing sedation, and those who are of advanced age.

KEYWORDS

Ethiopia, mechanical ventilation, mortality, Northwest Amhara, intensive care unit

Introduction

Worldwide, the number of patients needing mechanical ventilation (MV) in intensive care units (ICUs) is rising, especially among the elderly and patients with comorbid illnesses (1). Approximately half (40–50%) of patients admitted to the ICU need respiratory assistance with MV (2–6). Among those patients who received MV support in the ICU, a large number of patients, with a rough estimation of approximately 45–60%, will die in the hospital (4, 6, 7). MV is needed in patients with respiratory failure, but it is also associated with increased morbidity and mortality (8–10).

ICU expenses are significantly influenced by MV (11, 12), which accounts for a 25.8% increase in the daily costs of ICU care and accounts for approximately €1,580 for a single ventilated ICU day (12).

In contrast to high-income environments, the mortality rate of patients on MV among developing and low-income countries is higher (13–16). This can be related to the young and underdeveloped nature of intensive care medicine in these areas (17), as well as the lack of trained staff, equipment, and supply material resources (16, 17). According to a review of some studies, the mortality of MV patients ranges from 40.9 to 73.5% in Africa (14, 16, 18, 19). Previous studies conducted in Ethiopia revealed that the magnitude of mortality among mechanically ventilated patients ranges from 28.6 to 60.7% (20–23).

According to studies conducted globally, age (16, 21, 24, 25), sex (26, 27), inotrope and vasopressor use (7, 10, 20, 28, 29), increased duration on MV (10, 20, 23, 30), low serum albumin level (22, 25), decreased Glasgow coma scale score during ICU admission (22), comorbidity (14, 23, 25, 26, 31), need for dialysis (23, 25), multiple organ dysfunction syndrome (MODS) (30), sequential organ failure assessment (SOFA) score (7), acute physiology and chronic health evaluation (APACHE II) score (25, 32), positive end expiratory pressure (PEEP) (33), organ failure (32, 34), admission diagnosis (22, 34), sepsis (32, 35), readmission (36), reintubation (14), tracheostomy use (10, 29, 37), and sedation use (14, 20) were significant factors associated with mortality of mechanically ventilated patients in the ICU. Nevertheless, some of the severity scores, such as APACHE II and SOFA scores, are not applicable in the ICUs of our study settings yet.

Despite advances in the management of patients in the ICU and growing improvements in MV supply and utilization, the odds of mortality among critically ill patients receiving mechanical ventilation support remained higher than their non-ventilated counterparts (38). However, mortality was estimated to be higher in low-resource areas; most of the studies conducted in Ethiopia were concentrated in the capital city, where infrastructure is relatively better. The effect of management factors, such as initial ventilatory settings and reintubation, was also not well studied in those studies. Very little is known about the magnitude of mortality among patients on MV in the peripheral hospitals; thus, this study is aimed at assessing the mortality and its associated factors among mechanically ventilated adult patients in the ICUs of Northwest Amhara referral hospitals.

Materials and methods

Study design and period

An institution-based cross-sectional study design was employed through a review of the medical records of patients who were admitted from 1 February 2020 to 1 March 2023. The data were extracted from 10 April to 28 May 2023.

Study setting

The study was carried out at adult intensive care units of referral hospitals in Northwest Amhara, Ethiopia. In the northwest part of the Amhara region, there are five referral hospitals, including the University of Gondar Comprehensive Specialized Hospital (UOGCSH), Felege Hiwot Comprehensive Specialized Hospital (FHCSH), Debre Markos Comprehensive Specialized Hospital (DMCSH), Tibebe Gihon Comprehensive Specialized Hospital (TGCSH), and Debre Tabor Comprehensive Specialized Hospital (DTCSH). The catchment area for each referral hospital is thought to contain 5–7 million people (39). TGCSH is one of the teaching hospitals in Northwest Amhara, located in Bahirdar City, the capital of Amhara regional state, which is 565 km from the capital, Addis Ababa. There are two intensive care units (pediatric and adult). The adult ICU was equipped with 9 beds, 4 functioning mechanical ventilators, 7 patient monitors, and one bedside ultrasound. This unit is staffed with two anesthesiologists, internal medicine specialists and subspecialists, trained nurses, and medical and surgical residents (40). The pediatric ICU has two beds (41).

FHCSH is also the other referral hospital in Bahirdar City. The adult ICU is one of the 13 wards it has, where critically ill patients are admitted (41). Currently, it has 10 beds and 4 MVs. The UOGCSH is found in Gondar town, 700 km from Addis Ababa. UOGCSH started critical care service in 2011 with a four-bed ICU capacity, two motorized ventilators,

Abbreviations: AOR, Adjusted Odds Ratio; APACHE, Acute Physiology and Chronic Health Evaluation; ARDS, Acute Respiratory Distress Syndrome; CI, Confidence Interval; ICU, Intensive Care Unit; MODS, Multiple Organ Dysfunction Syndrome; MV, Mechanical Ventilation; PEEP, Positive End Expiratory Pressure; SOFA, Sequential Organ Failure Assessment; SPHMMC, Saint Paul's Hospital Millennium Medical College; SRMA, Systematic Review and Meta-Analysis; TASH, Tikur Anbessa Specialized Hospital; UOGCSH, University of Gondar Comprehensive Specialized Hospital; USA, United States of America; VAP, Ventilator Associated Pneumonia; VIF, Variance Inflation Factor.

one defibrillator, four non-invasive hemodynamic monitoring devices, and one ultrasound machine (42), and currently, it has four ICU departments divided based on specialty: medical ICU, surgical ICU, pediatrics ICU, and neonatal ICU. The adult medical and surgical ICUs of UOGCSH have 22 beds, 11 MVs, 22 monitors, 1 portable x-ray machine, 2 ultrasound machines, and 1 dialyzer machine. DTCSH is found in Debre Tabor town, the capital of the South Gondar zone. It is located approximately 665 km from the capital city of Ethiopia, Addis Ababa. It has three ICUs: 1 adult, 1 pediatric, and 1 neonatal. The adult ICU has 6 beds. DMCSH is located in East Gojam, which is located 300 km and 265 km from Addis Ababa and Bahir Dar, the capitals of Ethiopia and the Amhara regional state, respectively (43). The adult ICU has 4 beds, 3 functional mechanical ventilators, and 3 functional monitors.

Population

All adult patients admitted to the ICU and received mechanical ventilation support at referral hospitals in Northwest Amhara were the source population. All adult patients admitted to the ICU and received mechanical ventilation support at referral hospitals in Northwest Amhara from 1 February 2020 to 1 March 2023 were the study population. All adult patients admitted to the ICU and who received mechanical ventilation support from 1 February 2020 to 1 March 2023 were included in the study. Those patients who were mechanically ventilated for less than 24 h were excluded from the study. Patient charts with variables not recorded like ICU admission and discharge date, MV initiation time, socio-demographics such as age and sex, GCS during admission, and unknown outcome variable (not recorded and the patient left against medical advice or referred to other hospitals) were declared as incomplete and excluded from the study.

Sample size determination

For the first objective, a single population proportion formula was used to determine the sample size by taking a proportion, 57.1%, from a study in Saint Paul Hospital Millennium Medical College (SPHMMC) (23); d = margin of error, 5%, and Z α/2 = Z score of the 95% confidence level, 1.96.

$$n = \frac{Z^2_{(\alpha/2)}\, p(1-p)}{d^2}$$

$$n = \frac{(1.96)^2 (0.571)(0.429) = 377}{(0.05)^2}$$

For the second objective, the sample size was calculated as follows for significantly associated factors: sedation use, inotrope use, and duration of stay on MV (20), using Epi-info version 7.2.2.2, and the maximum sample size was 308. When comparing the sample sizes calculated for both objectives, the sample size obtained from the first objective (377) was found to be the highest. So, to get a maximum sample size, the sample size computed for the first objective was used.

A 15% contingency was considered for possible incomplete medical recording and possible lost charts, taking into account that a dead person's inactive charts would be difficult to access, and the final sample size was 434.

Sampling technique and procedures

All the five referral hospitals in the Northwest Amhara were included. After a proportional allocation of sample size made to the respective hospitals based on their 3-year data on MV use, a sampling frame was prepared using computer-generated random numbers by including all chart numbers of patients who were mechanically ventilated from February 2020 to March 2023. Finally, a simple random sampling technique was used to select the samples (Figure 1).

Operational definitions

MODS: Failure of two or more organs at any time in the ICU, depending on ODINS criteria (44).

Required Hemodialysis: Presence of two or more findings from the indications of dialysis below:

Electrolyte imbalance: Uncontrolled Hyperkalemia (potassium >6.5 mmoL/L or rising).

Serum sodium level < 115 or > 165 mmoL/L.

Edema (fluid overload): Refractory fluid overload.

Uremia: excessive blood urea nitrogen (BUN) and creatinine levels or any uremic abnormalities such as uremic encephalopathy, uremic pericarditis, and the like.

Acidosis: severe metabolic acidosis with concomitant acute kidney injury, pH < 7.

Intoxication: life-threatening poisoning with a dialyzable drug, such as salicylates, lithium, isopropanol, methanol, or ethylene glycol (45).

Barotrauma: Radiographically confirmed pneumothorax, pneumomediastinum, or subcutaneous emphysema that could not be attributed to iatrogenic injury (46).

Comorbidity is the co-occurrence of two or more disorders or diseases at the same time (47). Comorbidity was declared if the patient has at least one chronic illness other than the acute indication for MV.

Incomplete Patient Chart: Patients' charts were declared incomplete when they did not consist of complete baseline medical data, specifically for variables not recorded such as ICU admission date and discharge date, MV initiation time, socio-demographics such as age and sex, GCS during admission, and unknown outcome variables (not recorded and patient left against medical advice or referred to other hospitals).

Hypertension was defined as a blood pressure reading of systolic ≥130 and diastolic ≥80. At the same time, **Normotensive** was defined as a blood pressure reading of systolic 90–129 and diastolic 60–80 (48).

Hypotension was defined as a blood pressure reading of systolic <90 and diastolic <60 (49).

Tachypnea was defined as a respiratory rate > 30 breaths per minute (50).

Bradypnea was defined as a respiratory rate of <12 breaths per minute (51).

Sedation use was defined as having received an intravenous or intramuscular sedative (ketamine, benzodiazepines, dexmedetomidine, barbiturates, or propofol) for any period during the intensive care stay (52). This does not include the sedation used for procedures such as intubation.

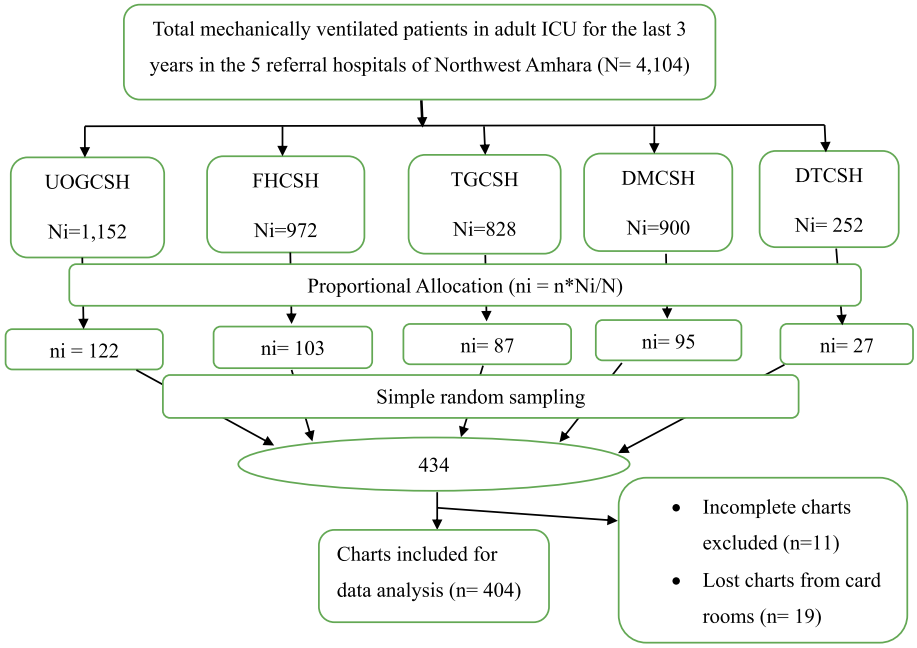

FIGURE 1
Schematic presentation of sampling procedures used to select mechanically ventilated patients in ICUs of referral hospitals in Northwest Amhara, Ethiopia, 2023.

Vasopressor use was defined as utilizing epinephrine, norepinephrine, vasopressin, dopamine, or phenylephrine (53) during ICU stay.

Data collection tool and procedures

A data extraction checklist was developed from mechanical ventilation protocols and related literature (10, 16, 20–23). The data extraction tool comprised socio-demographic data, such as age, sex, and residence; clinical characteristics such as admission diagnosis, GCS at admission, serum albumin level, hemoglobin level, sepsis, indication for MV, vital signs, presence and types of comorbidity, presence and types of organ failure, and presence of MODS; and management-related characteristics, such as readmission, reintubation, sedation use, vasopressor use, required dialysis, initial ventilatory settings, and duration of stay in ICU and on MV. Five trained BSc nurses working in emergency wards of the respective hospitals collected the data using the Kobo toolbox, a mobile and tablet-based data collection platform. Four trained MSc nurses working in wards other than the adult ICU supervised the data collection process. The patients' charts were found by taking the medical record number (MRN) from the log book at the ICU. Then, the charts were extracted from the card rooms of the corresponding hospitals. All randomly selected charts were roughly reviewed, and relevant data were extracted. For patients with readmission and reintubation, we used the last admission and intubation, respectively, to extract the data.

Data quality control

To control the quality of the data, data collectors and supervisors were trained separately for 2 days about the objectives of the study, confidentiality, and data collection techniques. The relevance of the variables in the tool was verified by consulting experts with a critical care specialty. Before the actual data collection, a preliminary chart review was conducted on 22 (5%) randomly selected charts at UOGCSH to check the accessibility of variables. Accordingly, variables that were repetitively not recorded in the patient recordings (inotrope use and I:E ratio) were excluded from the data extraction checklist. In addition, ventilation for less than 24 h was made as an exclusion criterion due to the absence of important variables for those ventilated for less than 24 h. During data collection, each filled checklist was cross-checked and revised daily by the investigator for completeness. Data cleaning was performed before analysis.

Data processing and analysis

After completion of data collection, the data were exported from the Kobo Toolbox Server into Microsoft Excel 2019 for data cleaning and management, and then it was exported to Stata 17 for data management and analysis. The descriptive statistics were described using texts, frequency tables, percentages, and graphs, whereas mean with standard deviation and median with interquartile ranges were used for continuous variables after the data distribution was checked by histogram and skewness and kurtosis tests to characterize study participants. Mean imputation was used to manage missing values for the continuous variables, baseline serum albumin level, baseline hemoglobin level, and temperature at the initiation of MV. The category of interest (died) was coded as 1 and survived was coded as 0. All relevant variables were included. The chi-square assumption test was done for categorical independent variables. Multicollinearity was checked by the variance inflation factor (VIF) and the variables; the presence of complication and VAP were excluded due to VIF > 10. Bivariable analysis was conducted using the binary logistic regression model to determine the association between each independent variable

and the outcome variable. Accordingly, variables with a p-value of ≤0.20 were considered for further analysis (multivariable analysis) to identify the net effect of each variable on the outcome variable. Finally, statistical significance was declared at $p < 0.05$, and the strength of associations was summarized using an adjusted odds ratio (AOR) with 95% confidence intervals (CI). The goodness of model fitness was checked using the Hosmer–Lemeshow goodness test.

Results

Socio-demographic characteristics of the study participants

A total of 404 charts of mechanically ventilated patients in the ICUs were included in the study, with a completeness rate of 93.1%. More than half (59.16%) of the patients were aged between 18 and 40 years, with a median age of 35.5 (IQR: 25–53). Two hundred twenty-five (55.69%) of the patients were male, and approximately 59.41% were rural residents (Table 1).

Clinical characteristics of the study participants

The main admission diagnosis for one-third of the study participants was respiratory, categorically. One hundred seventy-four (43.07%) of the study participants had a GCS of less than or equal to 8 or 7 with intubation (7T) during admission to the ICU. At the initiation of MV, more than half (62.13, 54.46, and 53.96%) of the patients were tachycardic, tachypneic, and hypoxic, respectively. Respiratory failure was the most common indication for MV (45.3%). Among the total study participants, the majority (81.44%) of them had at least one organ failure, and more than half (51.98%) had MODS. Only 87 (21.53%) patients had developed a complication, with VAP occupying the highest proportion (67.8%) (Table 2).

Management-related characteristics of the study participants

The median duration of ventilation for the study participants was 7 days (IQR: 3–12). Most of the patients (71.3%) had used sedatives, and nearly one-fourth (21.29%) of the patients were reintubated. The

TABLE 1 Socio-demographic characteristics of mechanically ventilated patients in the ICUs of referral hospitals in Northwest Amhara, Ethiopia, 2023 ($n = 404$).

Variables	Categories	Frequency	Percent (%)
Age	18–40	239	59.16
	41–70	132	32.67
	>70	33	8.17
Sex	Male	225	55.69
	Female	179	44.31
Residence	Rural	240	59.41
	Urban	164	40.59

TABLE 2 Clinical characteristics of mechanically ventilated patients in the ICUs of referral hospitals in Northwest Amhara, Ethiopia, 2023 ($n = 404$).

Variables	Categories	Frequency ($N = 404$)	Percent (%)
Main admission Diagnosis	Respiratory	136	33.66
	Cardiovascular	40	9.9
	Neurologic	80	19.8
	Renal	21	5.2
	Obstetric and gynecologic	26	6.44
	Surgical (non-trauma)	31	7.67
	Trauma	70	17.33
Presence of comorbidity	No	220	54.46
	Yes	184	45.54
Type of comorbidity ($N = 184$)	Chronic kidney disease	31	16.8
	Asthma	22	11.9
	Diabetes mellitus	33	17.9
	Hypertension	50	27.2
	COPD	9	4.9
	CHF	35	19
	HIV/AIDS	33	17.9
	Stroke	21	11.4
	Others*	9	4.9
GCS at ICU admission	≤8/7 T	174	43.07
	9–12/≥8 T	92	22.77
	13–15	138	34.16
Baseline serum albumin level	>2 g/dL	313	77.48
	≤2 g/dL	91	22.52
Baseline Hemoglobin level	≤7	38	9.41
	7.1–10	70	17.33
	10.1–13.5	198	49
	≥13.5	98	24.26
Blood pressure at initiation of MV	Hypotensive	129	31.93
	Hypertensive	84	20.8
	Normal	191	47.27
Heart rate at initiation of MV	Tachycardia	251	62.13
	Bradycardia	6	1.48
	Normal	147	36.39
Respiratory rate at initiation of MV	Tachypnea	220	54.46
	Bradypnea	5	1.24
	Normal	179	44.3
Temperature at initiation of MV	Normothermia	226	55.94
	Hypothermia	43	10.64
	Hyperthermia	135	33.42
Oxygen saturation at initiation of MV	Non-hypoxic	186	46.04
	Hypoxic	218	53.96

(Continued)

TABLE 2 (Continued)

Variables	Categories	Frequency (*N* = 404)	Percent (%)
Indication for MV	Neurologic/coma/ airway protection	145	35.9
	Neuromuscular diseases	40	9.9
	Respiratory failure	183	45.3
	Cardiovascular failure/ shock	36	8.9
Type of respiratory failure (*N* = 183)	Type 1	152	83.06
	Type 2	31	16.94
Organ failure presence	No	75	18.56
	Yes	329	81.44
Type of organ failure (*N* = 329)	Renal failure	90	27.35
	Respiratory failure	202	61.4
	Neurologic failure	140	42.5
	Cardiovascular failure	133	40.4
	Hematologic failure	34	10.3
	Hepatic failure	6	1.8
	Infectious failure	12	3.65
MODS	No	194	48.02
	Yes	210	51.98
Sepsis	No	242	59.9
	Yes	162	40.1
Complication developed	No	317	78.47
	Yes	87	21.53
Type of complication (*N* = 87)	VAP	59	67.8
	Barotrauma	8	9.2
	Pulmonary embolism	3	3.4
	ARDS	13	14.9
	Post-extubation stridor	5	5.7

Others*- Chronic liver disease, hepatitis, valvular heart disease, and epilepsy.

majority (87.87%) of the access to the airway was endotracheal tube and 46.53% of the patients were initiated by pressure control with assisted control mode. The median lengths of stay in the ICU and hospital for the study participants were 9 days (IQR: 5–15) and 12 days (IQR: 7–19), respectively. The mean initial Fi02 of the study participants was 83.28% ± 21.47 (Table 3).

Magnitude of mortality among mechanically ventilated adult patients in the ICU

In this study, the proportion of deaths among mechanically ventilated patients in the ICU was 254 (62.87%) with a 95% CI of (58.16–67.58) (Figure 2). The most common immediate cause of death registered was multiorgan failure, which accounts for 44.49% (Figure 3).

TABLE 3 Management-related characteristics of mechanically ventilated patients in the ICUs of referral hospitals in Northwest Amhara, Ethiopia, 2023 (*n* = 404).

Variables	Categories	Frequency (*N* = 404)	Percent (%)
Readmission	No	342	84.65
	Yes	62	15.35
Intubation time	Working day, daytime	174	43.07
	Working day, nighttime	137	33.9
	Weekend, daytime	63	15.6
	Weekend, nighttime	30	7.43
Reintubation	No	318	78.71
	Yes	86	21.29
Airway access	ET tube	355	87.87
	Tracheostomy	49	12.13
Initial mode of ventilation	PC/ AC	188	46.53
	VC/ AC	157	38.86
	SIMV	44	10.9
	CPAP	15	3.71
Duration of ventilation	1–10	272	67.33
	11–20	82	20.3
	>20	50	12.37
Length of stay in ICU	1–10	223	55.2
	11–20	112	27.72
	>20	69	17.08
Required hemodialysis	No	312	77.23
	Yes	92	22.77
Sedative use	No	116	28.7
	Yes	288	71.3
Vasopressor use	No	230	56.9
	Yes	174	43.1
Extubation time	Working day, daytime	192	47.5
	Working day, nighttime	100	24.8
	Weekend, daytime	47	11.6
	Weekend, nighttime	65	16.1

Factors associated with mortality of mechanically ventilated patients

In the multivariable logistic regression analysis, age (41–70), sepsis, reintubation, and sedation use were found to be significant factors associated with the mortality of mechanically ventilated patients at ICUs at a *p*-value <0.05.

Keeping all other variables constant, the odds of mortality among the 41–70 years age group was 4.3 (AOR, 4.28, 95% CI: 1.89–9.62) times higher than those in the 18–40 years age group. While controlling for other variables, the odds of mortality among patients with sepsis was 2.4 (AOR, 2.43, 95% CI: 1.08–5.46) times greater than those without sepsis. Patients who were reintubated were 2.8 (AOR, 2.76, 95% CI: 1.06–7.21) times more likely to die than those

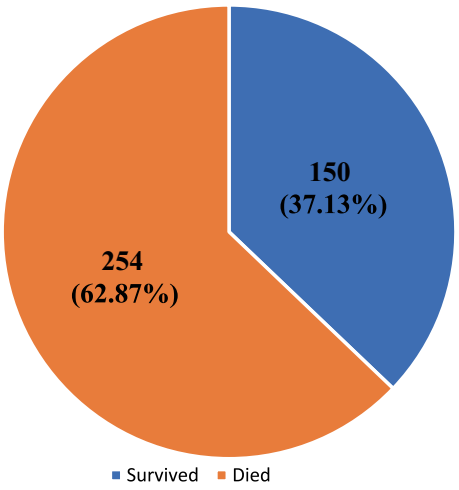

FIGURE 2
Magnitude of mortality among mechanically ventilated adult patients in the ICUs of referral hospitals in Northwest Amhara, Ethiopia, 2023.

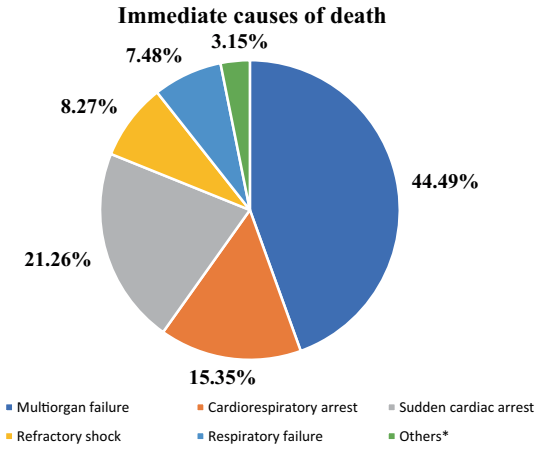

FIGURE 3
Registered causes of death among mechanically ventilated adult patients at ICUs of referral hospitals in Northwest Amhara, Ethiopia, 2023 ($n = 254$). Others*- Cardiovascular arrest, intracranial hemorrhage, and brain death.

non-reintubated patients, holding all other factors constant. However, using sedation decreased the odds of mortality by 59% (AOR, 0.41; 95% CI: 0.18–0.98) compared to patients not taking sedation, while other covariates remained the same (Table 4). The Hosmer–Lemeshow goodness of model fitness showed that the model is good-fitted at $p = 0.4510$ (Table 5). The mean VIF was found to be 2.28 (Table 6).

Discussion

In Ethiopia, patients who need mechanical ventilation were nearly five times more likely to die in the ICU than those who do not (38). Therefore, this study aimed to assess mortality and its associated factors among mechanically ventilated adult patients in intensive care units of referral hospitals in Northwest Amhara.

According to this study, the overall proportion of mortality among mechanically ventilated adult patients in the ICU was 62.87%, with a 95% CI of (58.16–67.58). This finding was higher than the observational study conducted in Argentina (44.6%) (35). This discrepancy might have resulted from a lack of standard illness severity scores and mortality predictions such as APACHE, which aid in anticipating mortality and considering special attention. The finding of this study was also higher than the study in Canada (18%) (54). In addition to differences in the quality of ICU care provided, this variation could be related to the difference in the study population; the study from Canada was conducted only on patients with acute respiratory failure, whereas the current study included all diagnoses. In this study, the proportion of mortality was higher than in the study conducted in Japan, 38.8% (55). The discrepancy could be due to exclusion criteria, as the study in Japan excluded patients who were mechanically ventilated for less than 3 days, cancer patients, and patients who stayed more than 60 days in the ICU. This might decrease the proportion since patients with an expected poor prognosis were excluded from the very beginning.

The proportion of mortality found in this study was also higher compared to similar studies in low-income countries. The finding of this study revealed that the mortality proportion of mechanically ventilated patients was greater than the study conducted in Egypt (40.9%) (14). The possible explanation for this discrepancy could be organizational structure since the study in Egypt was conducted specifically in the respiratory ICU, where management of mechanically ventilated patients will be more focused and organized. Similarly, the proportion of deaths found in this current study was higher than in previous studies conducted in Ethiopia; a multicenter study in Addis Ababa (41.7%) (20), SPHMMC (57.1%) (23), and Ayder Hospital, Mekelle (28.6%) (21). The study period, small sample size, lack of trained professionals (56), COVID-19 ICU burden, and the Northern Ethiopian conflict might have contributed to this high mortality. The study in Ayder Hospital, Mekelle, was conducted on relatively small sample sizes (105 samples). In addition to this, the study period in Ayder was free from both COVID-19 and the conflicting burden when ICU admission and the need for MV reached their peak.

However, the findings of this study showed a mortality proportion lower than that of a study conducted in India (83%) (57). This discrepancy could also be due to a difference in the study period; the previous study was conducted from 2013 to 2015, while our study is recent. The other possible justification for this discrepancy might be due to the presentation of the patients in the advanced stage of the disease having received poor or delayed pre-hospital care, leading to a poor outcome in these severely ill patients in the study in India (57).

Despite these discrepancies, this finding was comparable with a second study from a different center in India (67.21%) (34). The possible reason might be the similarity in inclusion criteria. Similar to the current study, the previous study also included patients greater than 18 years of age with all admission diagnoses. Similarly, the mortality proportion in this study was in line with a study conducted in TASH (60.7%) (22). This similarity could be due to similarities in admission diagnosis and indications; in both studies, respiratory problems and respiratory failure were the most common admission diagnoses and indications of MV, respectively. The mortality proportion in this study was in line with a study in Kenya (60.7%)

TABLE 4 Results of bivariable and multivariable logistic regression analysis of factors associated with the mortality of mechanically ventilated patients in adult ICUs of referral hospitals in Northwest Amhara, Ethiopia, 2023 ($n = 404$).

Variables	Mortality status		COR (95% CI)	AOR (95% CI)
	Died *n* (%)	Survived *n* (%)		
Age in years				
18–40	126 (52.72)	113 (47.28)	1	1
41–70	99 (75.0)	33 (25.0)	2.69 (1.68–4.29)	4.28 (1.89–9.62) *
>70	29 (87.88)	4 (12.12)	6.50 (2.22–19.07)	3.56 (0.73–17.39)
Serum albumin level				
>2 g/dL	179 (57.19)	134 (42.81)	1	1
≤ 2 g/dL	75 (82.42)	16 (17.58)	3.51 (1.96–6.29)	0.96 (0.38–2.43)
Blood pressure at the initiation of MV				
Hypotensive	103 (79.84)	26 (20.16)	4.54 (2.71–7.60)	2.13 (0.80–5.69)
Hypertensive	62 (73.81)	22 (26.19)	3.23 (1.84–5.67)	1.55 (0.63–3.81)
Normotensive	89 (46.6)	102 (53.4)	1	1
Admission GCS				
≤8/7 T	132 (75.86)	42 (24.14)	3.97 (2.45–6.43)	1.95 (0.68–5.59)
9–12/≥8 T	61 (66.3)	31 (33.7)	2.48 (1.44–4.29)	2.32 (0.96–5.62)
13–15	61 (44.2)	77 (55.8)	1	1
Admission diagnosis				
Respiratory	81 (59.56)	55 (40.44)	1	1
Cardiovascular	29 (72.5)	11 (27.5)	1.79 (0.82–3.88)	0.80 (0.19–3.28)
Neurologic	52 (65)	28 (35)	1.26 (0.71–2.24)	0.55 (0.15–1.99)
Renal	18 (85.71)	3 (14.29)	4.07 (1.14–14.50)	2.42 (0.39–15.17)
Obstetric/gynecologic	18 (69.23)	8 (30.77)	1.53 (0.62–3.76)	0.32 (0.06–1.62)
Surgical (non-trauma)	15 (48.39)	16 (51.61)	0.64 (0.29–1.39)	0.66 (0.13–3.27)
Trauma	41 (58.57)	29 (41.43)	0.96 (0.53–1.72)	0.65 (0.18–2.39)
Comorbidity				
No	103 (46.82)	117 (53.18)	1	1
Yes	151 (82.07)	33 (17.93)	5.19 (3.28–8.24)	2.47 (0.99–6.15)
Diabetes mellitus				
No	229 (61.73)	142 (38.27)	1	
Yes	25 (75.76)	8 (24.24)	1.94 (0.85–4.41)	0.72 (0.19–2.75)
Hypertension				
No	211 (59.6)	143 (40.4)	1	1
Yes	43 (86)	7 (14)	4.16 (1.82–9.51)	1.91 (0.47–7.81)
Congestive heart failure				
No	226 (61.25)	143 (38.75)	1	1
Yes	28 (80)	7 (20)	2.53 (1.08–5.95)	0.85 (0.19–3.75)
Hemoglobin level				
≤7	28 (73.68)	10 (26.32)	2.28 (1.00–5.20)	1.34 (0.27–6.78)
7.1–10	45 (64.29)	25 (35.71)	1.47 (0.78–2.76)	0.92 (0.29–2.89)
10.1–13.5	127 (64.14)	71 (35.86)	1.46 (0.89–2.39)	0.81 (0.36–1.82)
>13.5	54 (55.1)	44 (44.9)	1	1
Indication for MV				
Neurologic/coma/Airway protection	87 (60)	58 (40)	0.93 (0.59–1.45)	0.38 (0.08–1.67)

(Continued)

TABLE 4 (Continued)

Variables	Mortality status		COR (95% CI)	AOR (95% CI)
	Died *n* (%)	Survived *n* (%)		
Neuromuscular diseases	25 (62.5)	15 (37.5)	1.03 (0.51–2.09)	5.51 (0.89–33.98)
Respiratory failure	113 (61.75)	70 (38.25)	1	1
Cardiovascular failure/shock	29 (80.56)	7 (19.44)	2.57 (1.07–6.17)	0.62 (0.10–3.83)
Last temperature before initiation of MV				
Normothermia	131 (57.96)	95 (42.04)	1	1
Hypothermia	35 (81.4)	8 (18.6)	3.17 (1.41–7.15)	2.37 (0.72–7.77)
Hyperthermia	88 (65.19)	47 (34.81)	1.36 (0.87–2.11)	0.79 (0.38–1.66)
Organ failure				
No	26 (34.67)	49 (65.33)	1	1
Yes	228 (69.3)	101 (30.7)	4.25 (2.50–7.22)	2.12 (0.43–10.54)
Renal failure				
No	176 (56.05)	138 (43.95)	1	1
Yes	78 (86.67)	12 (13.33)	5.10 (2.67–9.74)	1.03 (0.20–5.16)
Respiratory failure				
No	120 (59.41)	82 (40.59)	1	1
Yes	134 (66.34)	68 (33.66)	1.35 (0.90–2.02)	0.70 (0.17–2.95)
Neurologic failure				
No	140 (53.03)	124 (46.97)	1	1
Yes	114 (81.43)	26 (18.57)	3.88 (2.38–6.34)	3.06 (0.67–14.04)
Cardiovascular failure				
No	141 (52.03)	130 (47.97)	1	1
Yes	113 (84.96)	20 (15.04)	5.21 (3.06–8.87)	1.73 (0.34–8.83)
Hematologic failure				
No	226 (61.08)	144 (38.92)	1	1
Yes	28 (82.35)	6 (17.65)	2.97 (1.20–7.36)	0.99 (0.18–5.65)
MODS				
No	71 (36.6)	123 (63.4)	1	1
Yes	183 (87.14)	27 (12.86)	11.74 (7.13–19.33)	2.96 (0.58–15.15)
Sepsis				
No	118 (48.76)	124 (51.24)	1	1
Yes	136 (83.95)	26 (16.05)	5.49 (3.37–8.97)	2.43 (1.08–5.46) *
Readmission				
No	200 (58.48)	142 (41.52)	1	1
Yes	54 (87.1)	8 (12.9)	4.79 (2.21–10.38)	2.84 (0.88–9.12)
Intubation time				
Working day, daytime	94 (54.02)	80 (45.98)	1	1
Working day, nighttime	92 (67.15)	45 (32.85)	1.74 (1.09–2.77)	1.41 (0.64–3.10)
Weekend, daytime	43 (68.25)	20 (31.75)	1.83 (0.99 3.36)	2.16 (0.77–6.08)
Weekend, nighttime	25 (83.33)	5 (16.67)	4.26 (1.56–11.63)	3.41 (0.79–14.55)
Reintubation				
No	186 (58.49)	132 (41.51)	1	1
Yes	68 (79.07)	18 (20.93)	2.68 (1.52–4.72)	2.76 (1.06–7.21)*
Initial ventilator mode				

(Continued)

TABLE 4 (Continued)

Variables	Mortality status		COR (95% CI)	AOR (95% CI)
	Died *n* (%)	Survived *n* (%)		
PC/AC	107 (56.91)	81 (43.09)	1	1
VC/AC	112 (71.34)	45 (28.66)	1.88 (1.20–2.96)	1.13 (0.53–2.40)
SIMV	23 (52.27)	21 (47.73)	0.83 (0.43–1.60)	1.12 (0.35–3.55)
CPAP	12 (80)	3 (20)	3.03 (0.83–11.08)	2.54 (0.27–24.26)
Initial FIO2	100% (IQR: 60–100)		0.99 (0.98–1.00)	0.99 (0.98–1.01)
Initial PEEP	6 (IQR: 5–8)		0.90 (0.81–0.99)	1.05 (0.88–1.24)
Required hemodialysis				
No	177 (56.73)	135 (43.27)	1	1
Yes	77 (83.70)	15 (16.30)	3.92 (2.16–7.11)	2.90 (0.72–11.65)
Sedation use				
No	92 (79.31)	24 (20.69)	1	1
Yes	162 (56.25)	126 (43.75)	0.34 (0.20–0.56)	0.41 (0.18–0.98) *
Vasopressor use				
No	113 (49.13)	117 (50.87)	1	1
Yes	141 (81.03)	33 (18.97)	4.42 (2.80–6.99)	1.64 (0.61–4.38)

*Statistically significant at $p < 0.05$; 1, reference; FI02, fraction of inspired oxygen; PEEP, positive end expiratory pressure; SIMV, synchronized intermittent mandatory ventilation; CPAP, continuous positive airway pressure; VC/AC, volume controlled assisted control; PC/AC, pressure controlled assisted control; MODS, multiple organ dysfunction syndrome; GCS, Glasgow Coma Scale; IQR, interquartile range; COR, crude odds ratio; AOR, adjusted odds ratio.

TABLE 5 Hosmer–Lemeshow goodness-of-fit test for the multivariable logistic regression analysis of factors associated with the mortality of mechanically ventilated patients in adult ICUs of referral hospitals in Northwest Amhara, Ethiopia, 2023 ($n = 404$).

Number of observations	404
Number of groups	10
Hosmer–Lemeshow chi2 (8)	7.82
Prob > chi2	0.4510

(16). Since both studies are conducted in peripheral hospitals with limited resources, the possible justification for this similarity could be due to the similar demography and socio-economic status of the study settings (56). It was also in line with a study in Cairo, Egypt (64%) (18).

This study revealed that age, presence of sepsis, sedation use, and reintubation were factors significantly associated with the mortality of mechanically ventilated patients in the ICU. Those in the 41–70 years age group had 4.3 times higher odds of mortality than those in the 18–40 years age group. This finding was consistent with previous studies conducted in India (34), Brazil (24), Kenya (16), Taiwan (25), Argentina (35), Addis Ababa, Ethiopia (31), and Mekelle, Ethiopia (21). This could be because older patients are more likely to experience acute respiratory failure, especially those over the age of 65 years (58), or due to declining physiologic reserve and function across multiple organ systems, which increases vulnerability to unfavorable health outcomes (59). Apart from this, it can also be related to a higher comorbidity burden among advanced-age patients (60).

According to our study, sepsis was also found to be a significant factor associated with the mortality of mechanically ventilated patients in ICUs. Patients who had sepsis had 2.43 times greater odds of mortality than those without sepsis. This finding was corroborated by the studies previously conducted in Argentina (35) and southern Brazil (32). The first reason could be that sepsis is a common cause of lung injury and increases lung susceptibility to ventilator-induced lung injury. Despite this fact, the specifics of the management of sepsis-induced lung injury are largely unknown (61). Second, ARDS is a devastating complication of severe sepsis, which is responsible for high mortality (62). Third, in addition to signs of infection, a host's response to an infection manifests with acute organ dysfunction, and this dysfunction can lead to multiple organ failure, acidosis, and death. Furthermore, sepsis can progress to its subset, septic shock, in which underlying circulatory, cellular, and metabolic abnormalities are profound enough to substantially increase the risk of mortality (63). Last but not least, the lack of sepsis assessment scales, such as quick sepsis-related organ failure assessment (qSOFA) and SOFA in our study settings, could also be a reason for this finding.

Reintubation was also another factor found to be significantly associated with the mortality of mechanically ventilated patients in ICUs. Patients who were reintubated had 2.8 times higher mortality odds than their non-reintubated counterparts. This result was in agreement with studies conducted in Egypt (14), Korea (64), the USA (65), and Brazil (66). This could be justified scientifically, as evidence from the SRMA (67) study revealed that reintubation increases the risk of acquiring VAP, which in turn increases the risk of mortality. Since intubation is an invasive procedure, we cannot deny that the repetitive action of this procedure will end up increasing the risk of intubation failure and complications such as VAP. The other possible reason might be unplanned extubation; the most common cause of reintubation was associated with more prolonged MV duration and ICU stays (64). The high reintubation rate in our study setting, which

TABLE 6 Results of multicollinearity test for factors associated with the mortality of mechanically ventilated patients in adult ICUs of referral hospitals in Northwest Amhara, Ethiopia, 2023 ($n = 404$).

Variable	Vif	1/Vif
Presence of comorbidity	5.39	0.185691
Respiratory failure	5.20	0.192342
MODS	4.84	0.206509
Cardiovascular failure	4.47	0.223793
Renal failure	4.34	0.230652
Duration of ventilation	3.75	0.266398
Neurologic failure	3.74	0.267292
Length of stay in ICU	3.33	0.300013
Oxygen saturation at initiation of MV	3.15	0.317129
Required hemodialysis	3.15	0.317955
Presence of organ failure	3.05	0.328366
Vasopressor use	2.67	0.374532
GCS at ICU admission	2.30	0.434746
HIV/AIDS	2.25	0.445293
Indication for MV	2.19	0.456595
Chronic kidney disease	2.18	0.457992
Hypertension	2.08	0.480453
Diabetes mellitus	2.03	0.492034
Main admission diagnosis	2.01	0.497492
Asthma	1.99	0.503646
Respiratory rate at initiation of MV	1.98	0.505784
Hematologic failure	1.85	0.539547
Baseline hemoglobin level	1.79	0.558254
Age of the patient	1.79	0.558537
Blood pressure at initiation of MV	1.76	0.568677
Congestive heart failure	1.74	0.573772
Presence of sepsis	1.71	0.584657
Reintubation	1.62	0.618082
Infectious failure	1.61	0.620387
Stroke	1.59	0.628897
Sedative use	1.57	0.635789
Airway access	1.55	0.643840
COPD	1.46	0.684478
Baseline serum albumin level	1.44	0.694144
Extubation time	1.38	0.725461
Initial PEEP	1.37	0.729806
Heart rate at initiation of MV	1.35	0.740303
Initial mode of ventilation	1.29	0.777353
Readmission	1.26	0.795441
Sex of the patient	1.25	0.801868
Temperature at the initiation of MV	1.24	0.805046
Hepatic failure	1.23	0.813025
Residence	1.23	0.815161
Intubation time	1.22	0.817741
Mean Vif	2.28	

in turn might be caused by the lack of a well-established comprehensive extubation protocol, could also be the reason.

According to this study, sedation use was revealed as an important factor significantly associated with the mortality of mechanically ventilated patients. The odds of mortality among patients who used sedation decreased by 59% compared to those who were not sedated. This finding is supported by a previous study conducted in Ethiopia (20). This might be because if agitated patients do not get sedated, they might extubate themselves, fight against restraints, and increase the risk of injury. The work of breathing also increases, thereby standing against the main goal of MV and delaying recovery. Wise use of sedation guided by the Richmond Agitation-Sedation Scale assists in the control of sedation, which favors patient care and recovery as well as guides nurses' decision-making (68). Contrary to this, a study in Egypt (14) showed that patients who used sedatives for 24 h or more had higher odds of mortality than those who did not. This might be due to the intensity of the sedation. Sedation intensity independently, in an ascending relationship, predicted an increased risk of death, delirium, and delayed time to extubation (69). The deeper the patient is sedated, the higher the risk of death and delayed extubation. Many researchers concur that keeping sedation levels equivalent to the Richmond Agitation Sedation Scale, 0, is a clinically desirable goal. They suggest adequately sedating mechanically ventilated patients while balancing against the known negative consequences of excessive sedation (70–73).

Limitations of the study

Since secondary data review was used, socio-economic, personal, nutritional status, and other socio-demographic characteristics were not explicitly included in this study. The effects of some important predictor parameters of mortality, such as APACHE, SOFA, and qSOFA, were not determined due to the inapplicability of the scores.

Conclusion

The overall magnitude of mortality in mechanically ventilated patients was high. The main factors associated with increased mortality were advanced age, sepsis, and reintubation history. Hence, special attention to the elderly, patients with sepsis, and reintubated patients could minimize mortality. However, sedation use was found to be associated with decreased mortality odds. In order to calculate and utilize severity scores in the ICU, we recommend having investigation materials such as arterial blood gas analysis in these hospitals. Strengthening the use of sedation scales such as the Richmond agitation sedation scale for MV patients is recommended, and it is better to set a well-established systematic and comprehensive extubation protocol to decrease mortality of mechanically ventilated patients.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the School of Nursing Ethical Review Committee at College of Medicine and Health Sciences, University of Gondar. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

ET: Writing – original draft, Software, Resources, Investigation, Formal analysis, Conceptualization. AT: Writing – review & editing, Methodology, Investigation, Conceptualization. NY: Writing – review & editing, Methodology, Investigation, Conceptualization. TN: Writing – review & editing, Software, Investigation, Formal analysis, Data curation. TM: Writing – review & editing, Supervision, Methodology, Investigation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Ghauri SK, Javaeed A, Mustafa KJ, Khan AS. Predictors of prolonged mechanical ventilation in patients admitted to intensive care units: a systematic review. *Int J Health Sci*. (2019) 13:31–8.

2. Bellani G, Laffey JG, Pham T, Fan E, Brochard L, Esteban A, et al. Epidemiology, patterns of care, and mortality for patients with acute respiratory distress syndrome in intensive care units in 50 countries. *JAMA*. (2016) 315:788–800. doi: 10.1001/jama.2016.0291

3. Esteban A, Anzueto A, Alia I, Gordo F, Apezteguia C, Palizas F, et al. How is mechanical ventilation employed in the intensive care unit? *Am Rev Respir Dis*. (2000) 161:1450–8. doi: 10.1164/ajrccm.161.5.9902018

4. Esteban A, Anzueto A, Frutos F, Alía I, Brochard L, Stewart TE, et al. Characteristics and outcomes in adult patients receiving mechanical ventilation: a 28-day international study. *JAMA*. (2002) 287:345–55. doi: 10.1001/jama.287.3.345

5. Fernando SM, McIsaac DI, Rochwerg B, Bagshaw SM, Muscedere J, Munshi L, et al. Frailty and invasive mechanical ventilation: association with outcomes, extubation failure, and tracheostomy. *Eur J Intensive Care Med*. (2019) 45:1742–52. doi: 10.1007/s00134-019-05795-8

6. Henry O, Amata AO. A 2-year review of admissions to the intensive care unit of the georgetown public hospital corporation, Guyana. *West Indian Med J*. (2016) 66:628. doi: 10.7727/wimj.2015.335

7. Roedl K, Jarczak D, Thasler L, Bachmann M, Schulte F, Bein B, et al. Mechanical ventilation and mortality among 223 critically ill patients with coronavirus disease 2019: a multicentric study in Germany. *Confed Aust Crit Care Nurses J*. (2021) 34:167–75. doi: 10.1016/j.aucc.2020.10.009

8. Kobayashi H, Uchino S, Takinami M, Uezono SJRC. The impact of ventilator-associated events in critically ill subjects with prolonged mechanical ventilation. *Respir Care*. (2017) 62:1379–86. doi: 10.4187/respcare.05073

9. Pisani L, Algera AG, Neto AS, Ahsan A, Beane A, Chittawatanarat K, et al. Epidemiological characteristics, ventilator management, and clinical outcome in patients receiving invasive ventilation in intensive care units from 10 Asian middle-income countries (PRoVENT-iMiC): an international, multicenter, prospective study. *J Nat Malaria Soc*. (2021) 104:1022–33. doi: 10.4269/ajtmh.20-1177

10. Tobi K, Ekwere I, Ochukpe CJJACR. Mechanical ventilation in the intensive care unit: a prospective study of indications and factors that affect outcome in a tertiary hospital in Nigeria. *J Anesth Clin Res*. (2017) 8:2.

11. Gümüş A, Çilli A, Çakın Ö, Karakurt Z, Ergan B, Aksoy E, et al. Factors affecting cost of patients with severe community-acquired pneumonia in intensive care unit, *Turkish Thoracic journal* (2019) 20:216.

12. Kaier K, Heister T, Motschall E, Hehn P, Bluhmki T, Wolkewitz MJE, et al. Impact of mechanical ventilation on the daily costs of ICU care: a systematic review and meta regression. *J Hyg*. (2019) 147:e314. doi: 10.1017/S0950268819001900

13. Bacha T, Tsegaye N, Tuli W. Utilization of mechanical ventilators in low resource faculty: a cross sectional study. (2020).

14. el-Shahat H, Salama S, Wafy S, Bayoumi H. Risk factors for hospital mortality among mechanically ventilated patients in respiratory ICU. *Egypt J Bronchol*. (2015) 9:231–7. doi: 10.4103/1687-8426.165895

15. Khedr A, Al Hennawi H, Rauf I, Khan MK, Mushtaq HA, Lodhi HS, et al. Differential mortality with COVID-19 and invasive mechanical ventilation between high-income and low-and middle-income countries: a systematic review, meta-analysis, and meta-regression. *Infez Med*. (2022) 30:51–8. doi: 10.53854/liim-3001-6

16. Parker RK, Mwachiro EB, Mwachiro MM, Pletcher J, Parker AS, Many HR. Mortality prediction in rural Kenya: a cohort study of mechanical ventilation in critically ill patients. *CCE J*. (2019) 1:e0067. doi: 10.1097/CCE.0000000000000067

17. Dondorp AM, Iyer SS, Schultz MJJJ. Critical care in resource-restricted settings. *JAMA*. (2016) 315:753–4. doi: 10.1001/jama.2016.0976

18. Nassar YS, Magdy M, Hamed L, Algohary T. A 5-year registry of mechanically ventilated patients comprising epidemiology, initial settings, and clinical outcome. *Egypt J Chest Dis Tuberc*. (2018) 67:250. doi: 10.4103/ejcdt.ejcdt_34_18

19. Ttendo SS, Was A, Preston MA, Munyarugero E, Kerry VB, Firth PG. Retrospective Descriptive Study of an Intensive Care Unit at a Ugandan Regional Referral Hospital. *World J Surg*. (2016) 40:2847–56. doi: 10.1007/s00268-016-3644-5

20. Alemayehu M, Azazh A, Hussien H, Baru AJOAEM. Characteristics and outcomes of mechanically ventilated patients at adult ICU of selected public hospitals in Addis Ababa, Ethiopia. *Open Access Emerg Med*. (2022) 14:395–404. doi: 10.2147/OAEM.S369752

21. Berhe E. Clinical characteristics and outcomes of patients under invasive mechanical ventilation at Ayder comprehensive specialized hospital adult intensive care unit, Mekelle, Ethiopia. *Eur Respiratory Soc*. (2018) 52:PA333. doi: 10.1183/13993003.congress-2018.PA333

22. Debebe F, Goffi A, Haile T, Alferid F, Estifanos H, Adhikari NKJCCR, et al. Predictors of ICU mortality among mechanically ventilated patients: an inception cohort study from a tertiary care center in Addis Ababa, Ethiopia. *Crit Care Res Pract*. (2022) 2022:7797328. doi: 10.1155/2022/7797328

23. Hunegnaw W, Bayisa T. Outcome of mechanical ventilator use and associated factors at Saint Paul's hospital millennium medical college medical intensive care unit. *MJH*. (2022) 1

24. Azevedo LC, Park M, Salluh JI, Rea-Neto A, Souza-Dantas VC, Varaschin P, et al. Clinical outcomes of patients requiring ventilatory support in Brazilian intensive care units: a multicenter, prospective, cohort study. *Crit Care*. (2013) 17:R63. doi: 10.1186/cc12594

25. Lai C-C, Shieh J-M, Chiang S-R, Chiang K-H, Weng S-F, Ho C-H, et al. The outcomes and prognostic factors of patients requiring prolonged mechanical ventilation. *Sci Rep*. (2016) 6:1–6. doi: 10.1038/srep28034

26. Chang R, Elhusseiny KM, Yeh Y-C, Sun WZ. COVID-19 ICU and mechanical ventilation patient characteristics and outcomes—A systematic review and meta-analysis. *PLoS One*. (2021) 16:e0246318. doi: 10.1371/journal.pone.0246318

27. Uy ABC, Ramos EFP, Rivera AS, Maghuyop NL, Suratos CTR, Miguel RTD, et al. Incidence, risk factors, and outcomes of unplanned extubation in adult patients in a resource-limited teaching hospital in the Philippines: a cohort study. *Crit Care Sc*. (2019) 31:79–85. doi: 10.5935/0103-507X.20190012

28. Dettmer MR, Damuth E, Zarbiv S, Mitchell JA, Bartock JL, Trzeciak S. Prognostic factors for long-term mortality in critically ill patients treated with prolonged mechanical ventilation: a systematic review. *Crit Care Med*. (2017) 45:69–74. doi: 10.1097/CCM.0000000000002022

29. Yadav V, Jadhao G, Salame RN. Aetiology and predictors of outcome of mechanically ventilated patients admitted in intensive care unit of a rural tertiary health care center. *Int J Biomed Adv Res*. (2018) 9:265.

30. Bacha T, Tsegaye N, Tuli W. Characteristics and outcomes of mechanically ventilated pediatric patients in a Tertiary Referral Hospital, Addis Ababa, Ethiopia: Cross sectional study. *Ethiop J Health Sci*. (2021) 31:915–24. doi: 10.4314/ejhs.v31i5.2

31. Nega G, Sibhat M, Mekonnen A, Techane TJF. Survival status and predictors of mortality among mechanically ventilated COVID-19 patients in Addis Ababa COVID-19 Care Centers, Ethiopia: a survival analysis. *F1000 Fac Rev*. (2022) 11:1329. doi: 10.12688/f1000research.124586.1

32. Fialkow L, Farenzena M, Wawrzeniak IC, Brauner JS, Vieira SRR, Vigo A, et al. Mechanical ventilation in patients in the intensive care unit of a general university hospital in southern Brazil: an epidemiological study. *Revista do Hospital das Clínicas*. (2016) 71:145–51. doi: 10.6061/clinics/2016(03)05

33. Guo L, Xie J, Huang Y, Pan C, Yang Y, Qiu H, et al. Higher PEEP improves outcomes in ARDS patients with clinically objective positive oxygenation response to PEEP: a systematic review and meta-analysis. *Anesthesiology*. (2018) 18:172–11. doi: 10.1186/s12871-018-0631-4

34. Khatib KI, Dixit SB, Joshi MM. Factors determining outcomes in adult patient undergoing mechanical ventilation: a "real-world" retrospective study in an Indian Intensive Care Unit. *Int J Crit Illn Inj Sci*. (2018) 8:9–16. doi: 10.4103/IJCIIS.IJCIIS_41_17

35. Plotnikow G, Gogniat E, Accoce M, Navarro E, Dorado J, Intensiva ESGJM. Epidemiology of mechanical ventilation in Argentina. The EpVAr multicenter observational study. *Med Intensiva*. (2022) 46:372–82. doi: 10.1016/j.medine.2022.05.002

36. de-Miguel-Díez J, Jiménez-García R, Hernández-Barrera V, Zamorano-Leon JJ, Villanueva-Orbaiz R, Albaladejo-Vicente R, et al. Trends in mechanical ventilation use and mortality over time in patients receiving mechanical ventilation in Spain from 2001 to 2015. *Eur J Intern Med*. (2020) 74:67–72. doi: 10.1016/j.ejim.2019.11.023

37. Tilahun L, Molla A, Ayele FY, Nega A, Dagnaw K. Time to recovery and its predictors among critically ill patients on mechanical ventilation from intensive care unit in Ethiopia: a retrospective follow up study. *Emerg Med*. (2022) 22:1–11. doi: 10.1186/s12873-022-00689-3

38. Endeshaw AS, Tarekegn F, Bayu HT, Ayalew SB, Gete BC. The magnitude of mortality and its determinants in Ethiopian adult intensive care units: a systematic review and meta-analysis. *AMS*. (2022) 84:104810. doi: 10.1016/j.amsu.2022.104810

39. Fentie EA, Yeshita HY, Bokie MM. Low birth weight and associated factors among HIV positive and negative mothers delivered in northwest Amhara region referral hospitals, Ethiopia, 2020 a comparative crossectional study. *PLoS One*. (2022) 17:e0263812. doi: 10.1371/journal.pone.0263812

40. Demass TB, Guadie AG, Mengistu TB, Belay ZA, Melese AA, Berneh AA, et al. The Burden of intensive care unit mortality and the Predictors in Amhara regional state, Northwest Ethiopia. (2022).

41. Belay CM, Zewale TA, Amlak BT, Abebe TG, Hailu G. Incidence and predictors of ventilator-associated pneumonia among adult intubated patients in Bahir Dar Specialized Hospitals, 2021: a retrospective follow-up study. *Int J Gen Med*. (2022) 15:8173–82. doi: 10.2147/IJGM.S380301

42. Tesema HG, Lema GF, Mesfin N, Fentie DY, Arefayne NR. Patterns of admission and clinical outcomes among patients admitted to medical intensive care unit of a teaching and referral hospital, Northwest Ethiopia. *Glob Adv Integr Med Health*. (2021) 10:216495612198925. doi: 10.1177/2164956121989258

43. Dagnew SB, Tadesse TY, Zeleke MM, Yiblet TG, Addis GT, Mekonnen GB, et al. Drug–drug interactions among hospitalized elderly in patients at medical wards of Northwest Ethiopia's Comprehensive Specialized Hospitals: a multicenter observational study. *Open Med*. (2022) 10:205031212211358. doi: 10.1177/20503121221135874

44. Rapsang AG, Shyam DC. Scoring systems in the intensive care unit: a compendium. *Crit Care Med*. (2014) 18:220–8. doi: 10.4103/0972-5229.130573

45. Tintinalli JE, Ma OJ, Yealy DM, Meckler GD, Stapczynski JS, Cline DM, et al. Tintinalli's emergency medicine, a comprhenssive study guide. 9th ed (2020).

46. Berhe E, Gebrehiwet TG, Teka H, Gebrehiwot KG, Abraha HE, Tequare MH. Clinical characteristics and determinants of invasive mechanical ventilation outcome in adult intensive care unit in Northern Ethiopia: a resource-limited setting. *JPATS*. (2023) 4:11–21. doi: 10.25259/JPATS_35_2022

47. Dewey D. What is comorbidity and why does it matter in neurodevelopmental disorders? *Curr Dev Disord Rep*. (2018) 5:235–42. doi: 10.1007/s40474-018-0152-3

48. Casey DE Jr, Thomas RJ, Bhalla V, Commodore-Mensah Y, Heidenreich PA, Kolte D, et al. 2019 AHA/ACC clinical performance and quality measures for adults with high blood pressure: a report of the American College of Cardiology/American Heart Association Task Force on Performance Measures. *J Am Coll Cardiol*. (2019) 12:e000057.

49. Assele DD, Lendado TA, Awato MA, Workie SB, Faltamo WF. Incidence and predictors of mortality among patients with head injury admitted to Hawassa University Comprehensive Specialized Hospital, Southern Ethiopia: A retrospective follow-up study. *PLoS One*. (2021) 16:e0254245. doi: 10.1371/journal.pone.0254245

50. Rahimzadeh P, Faiz HR, Farahmandrad R, Hassanlouei B, Habibi A, Hedayati Emami S, et al. Clinical features and prognosis of invasive ventilation in hospitalized patients with COVID-19: a retrospective study. *Anesthesiol Pain Med*. (2020) 10:e108773. doi: 10.5812/aapm.108773

51. Yeh J, McKee C, Chenault K, Tobias JD. Remimazolam as a primary agent for brief invasive and noninvasive procedures: a case series. *JOCMR*. (2023) 15:174–80. doi: 10.14740/jocmr4870

52. Wunsch H, Kahn JM, Kramer AA, Wagener G, Li G, Sladen RN, et al. Dexmedetomidine in the care of critically ill patients from 2001 to 2007: an observational cohort study. *Anesthesiology*. (2010) 113:386–94. doi: 10.1097/ALN.0b013e3181e74116

53. Nair RM, Saleem T, Kumar S, Das TM, Higgins A, Lee R, et al. Short term outcomes of patients with cardiogenic shock on mechanical circulatory support stratified by vasopressor use, *Journal of the American college of cardiology* (2023) 81:579. doi: 10.1016/S0735-1097(23)01023-9,

54. Urner M, Jüni P, Hansen B, Wettstein MS, Ferguson ND, Fan EJTLRM. Time-varying intensity of mechanical ventilation and mortality in patients with acute respiratory failure: a registry-based, prospective cohort study. *Respir Med*. (2020) 8:905–13. doi: 10.1016/S2213-2600(20)30325-8

55. Iwashita Y, Yamashita K, Ikai H, Sanui M, Imai H, Imanaka YJCC. Epidemiology of mechanically ventilated patients treated in ICU and non-ICU settings in Japan: a retrospective database study. *Crit Care*. (2018) 22:329–9. doi: 10.1186/s13054-018-2250-3

56. Haniffa R, Pubudu de Silva A, de Azevedo L, Baranage D, Rashan A, Baelani I, et al. Improving ICU services in resource-limited settings: perceptions of ICU workers from low-middle-, and high-income countries. *J Crit Care*. (2018) 44:352–6. doi: 10.1016/j.jcrc.2017.12.007

57. Chiwhane A, Diwan S. Characteristics, outcome of patients on invasive mechanical ventilation: a single center experience from central India. *Egypt J Crit Care Med*. (2016) 4:113–8. doi: 10.1016/j.ejccm.2016.10.003

58. Behrendt CEJC. Acute respiratory failure in the United States: incidence and 31-day survival. *Dis Chest*. (2000) 118:1100–5. doi: 10.1378/chest.118.4.1100

59. Leng S, Chen X, Mao G, Leng S. Frailty syndrome: an overview. *Clin Interv Aging*. (2014) 9:433–41. doi: 10.2147/CIA.S45300

60. Smolin B, Raz-Pasteur A, Mashiach T, Zaidani H, Levi L, Strizevsky A, et al. Mechanical ventilation for older medical patients in a large tertiary medical care center. *EGM*. (2022) 13:253–65. doi: 10.1007/s41999-021-00557-6

61. Zampieri FG, Mazza BJS. Mechanical ventilation in sepsis: a reappraisal. *Shock*. (2017) 47:41–6. doi: 10.1097/SHK.0000000000000702

62. Kim W-Y, Hong SB. Sepsis and acute respiratory distress syndrome: recent update. *Kyŏrhaek mit hohŭpki chirhwan*. (2016) 79:53–7. doi: 10.4046/trd.2016.79.2.53

63. Cecconi M, Evans L, Levy M, Rhodes AJTL. Sepsis and septic shock. *Lancet*. (2018) 392:75–87. doi: 10.1016/S0140-6736(18)30696-2

64. Lee J-H, Lee H-C, Jeon Y-T, Hwang J-W, Lee H, Oh H-W, et al. Clinical outcomes after unplanned extubation in a surgical intensive care population. *Bulletin de la Société International de Chirurgie*. (2014) 38:203–10. doi: 10.1007/s00268-013-2249-5

65. Karamanos E, Schmoekel N, Blyden D, Falvo A, Rubinfeld IJPJ. Association of unplanned reintubation with higher mortality in old, frail patients: a national surgical quality-improvement program analysis. *Perm J*. (2016) 20:16–017. doi: 10.7812/TPP/16-017

66. dos Anjos Agostini AR, IdFS B, Tonella RM, Dos Santos AH, Falcão AE, Logato CM, et al. Mortality predictors after liver transplant in the intensive care unit. Transplantation Proceedings Elsevier (2018).

67. Gao F, Yang L-H, He H-R, Ma X-C, Lu J, Zhai Y-J, et al. The effect of reintubation on ventilator-associated pneumonia and mortality among mechanically ventilated

patients with intubation: a systematic review and meta-analysis. *Heart Lung*. (2016) 45:363–71. doi: 10.1016/j.hrtlng.2016.04.006

68. Barbosa TP, Beccaria LM, Bastos AS, Silva D. Association between sedation level and mortality of intensive care patients on mechanical ventilation. *Rev Esc Enferm USP*. (2020) 54:e03628. doi: 10.1590/S1980-220X2019006903628

69. Shehabi Y, Bellomo R, Kadiman S, Ti LK, Howe B, Reade MC, et al. Sedation intensity in the first 48 hours of mechanical ventilation and 180-day mortality: a multinational prospective longitudinal cohort study. *Crit Care Med*. (2018) 46:850–9. doi: 10.1097/CCM.0000000000003071

70. Pearson SD, Patel BK. Evolving targets for sedation during mechanical ventilation. *Curr Opin Crit Care*. (2020) 26:47–52. doi: 10.1097/MCC.0000000000000687

71. Su J-Y, Lockwood C, Tsou Y-C, Mu P-F, Liao S-C, Chen WC. Implementing the Richmond Agitation-Sedation Scale in a respiratory critical care unit: a best practice implementation project. *JBI Database System Rev Implement Rep*. (2019) 17:1717–26. doi: 10.11124/JBISRIR-2017-004011

72. Taran Z, Namadian M, Faghihzadeh S, Naghibi T. The effect of sedation protocol using Richmond Agitation-Sedation Scale (RASS) on some clinical outcomes of mechanically ventilated patients in intensive care units: a randomized clinical trial. *JCS*. (2019) 8:199–206. doi: 10.15171/jcs.2019.028

73. Yousefi H, Toghyani F, Yazdannik AR, Fazel K. Effect of using Richmond Agitation Sedation Scale on duration of mechanical ventilation, type and dosage of sedation on hospitalized patients in intensive care units. *Iran J Nurs Midwifery Res*. (2015) 20:700–4. doi: 10.4103/1735-9066.170008

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Healthcare providers' knowledge, attitude, and practice towards cervical cancer screening in Sub-Saharan Africa: systematic review and meta-analysis

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Introduction: Cervical cancer is a prevalent cancer among women in low and middle-income countries, but it can be largely prevented through screening programs and HPV vaccination. This study aimed to determine the level of knowledge, attitudes, and practices regarding cervical cancer screening among healthcare providers in Sub-Saharan African countries.

Methods: Systematic review and meta-analysis were conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines. Relevant databases including PubMed, Cochrane Library, AJOL, Google Scholar, and ScienceDirect databases were used to retrieve and search articles. The study included published and unpublished research written in English between January 2013 and May 16, 2024 for studies reporting knowledge, attitude, and practice towards cervical cancer screening among healthcare providers in Sub-Saharan Africa. This review has been registered on PROSPERO. The heterogeneity of the data was evaluated using the I^2 statistic. A meta-analysis was conducted using STATA 17 software, with a 95% confidence interval. The researchers also conducted publication bias and sensitivity analysis.

Abbreviations: CIl, Confidence interval; HPV, Human Papilloma Virus Infection; OR, Odds Ratio; PRISMA, Preferred Reporting Items for Systematic Review and Meta-Analysis; VIA, Visual Inspection with Acetic acid; VILI, Visual Inspection Lugol's Iodine.

Results: The review included 30 studies involving 7542 healthcare providers. The pooled magnitude of good knowledge status towards cervical cancer was 67.93% (95% CI: 53.36–82.50) whereas the pooled magnitude of positive attitude towards cervical cancer was 55.26% (95% CI: 34.28– 76.23). The results also showed that about 49.68% (95% CI: 33.18–66.17) of healthcare providers had good knowledge status about cervical cancer screening, 66.63%(95% CI: 50.36– 82.89) had a positive attitude towards it, and only 17.23% (95% CI; 6.08-28.37) had ever screened for cervical cancer.

Conclusion: The overall magnitude of knowledge and attitude of healthcare providers in Sub-Saharan Africa towards cervical cancer and its screening was suboptimal. Furthermore, a low percentage of female healthcare providers in the region had undergone screening for cervical cancer. As a result, policymakers and program administrators should focus on improving the knowledge, attitude, and practices of healthcare providers to meet the global health goal of cervical cancer screening and effectively eliminating cervical cancer. Healthcare providers must serve as role models for other women who should also undergo screening.

Systematic review registration: https://www.crd.york.ac.uk/PROSPERO/, identifier CRD42023495241.

KEYWORDS

cervical cancer screening, healthcare provider, knowledge, attitude, practice, sub-Saharan Africa

Introduction

Cervical cancer is the fourth most prevalent cancer among women on a global scale, comprising approximately 604,000 new cases and leading to 342,000 deaths worldwide (1). The majority of deaths from cervical cancer occur in underdeveloped or developing countries, accounting for about 85% of the total. In low-income and middle-income countries, the death rate from cervical cancer is 18 times higher compared to wealthier countries (2). The number of new cases and deaths from cervical cancer in sub-Saharan Africa is expected to increase over the next 20 years starting from 2013 (3). In comparison, Northern Africa has made significant progress in reducing the occurrence and death rate of cervical cancer, making it the region with the lowest rates in Africa (4).

The risk factors for cervical cancer consist of human papillomavirus infection (HPV), having multiple sexual partners, starting sexual activity at a young age, giving birth to multiple children, having a low socioeconomic status, and smoking tobacco (5–7). Around 70% of cervical cancer cases can be attributed to HPV types 16 and 18 (8). HPV disrupts the normal activity of cells, causing noticeable alterations in the epithelial cells located in the transformation zone of the cervix (9). It is the most common sexually transmitted infection globally. It is most frequently found in teenage and young adult women, which aligns with the timing of their first sexual experiences (10).

This cancerous disease takes a long time to develop into malignant tumors, with the presence of precancerous lesions indicating the ongoing infection (11). It takes between 10 to 15 years for cervical cancer to develop (12). Cervical cancer is a fatal illness when it becomes invasive, but it can be prevented through effective screening programs by identifying and treating premalignant lesions (13). Although vaccines can provide significant protection against HPV for women who have never been exposed to the virus, such as young girls and teenagers, those who have previously been vaccinated will still need to undergo cervical cancer screening later in life to protect against other strains of HPV not included in the vaccines (14). There are several methods for cervical screening, including Pap smear test, HPV DNA test, visual inspection with acetic acid (VIA), or visual inspection with Lugol's iodine (VILI) (15–19). Properly identifying precancerous lesions and HPV infection through cervical cancer screening methods could significantly decrease cervical cancer deaths (20).

The World Health Assembly has adopted the Global Strategy for eliminating cervical cancer, aiming to achieve it by 2030. This strategy includes three global targets known as 90-70-90, which aim to have 90% of girls vaccinated against HPV by the age of 15, screen 70% of women aged 35-45, and provide treatment to 90% of women diagnosed with cervical disease (21). This strategy aims to eradicate cervical cancer as a major public health issue worldwide, with a goal of reducing the incidence rate to below 4 cases per 100,000 women per year. A global plan to eliminate cervical cancer by 2030 in low- and lower-middle-income countries is projected to reduce the incidence rate by 42% by 2045 and 97% by 2120, preventing over

74 million new cases. Additionally, it is estimated that 300,000 cervical cancer deaths will be prevented by 2030, with over 62 million deaths averted by 2120 (21). The World Health Organization recommends that women in the general population begin cervical cancer screening at age 30. However, women with HIV should be screened more often (every 3 to 5 years) due to their significantly higher risk of developing cervical cancer. For women who receive negative results on VIA or cytology tests, it is recommended to undergo regular screening every three to five years. In women who test negative on an HPV test, rescreening should be done after a minimum interval of five years (22). Healthcare providers are vital in educating people about the risk factors and prevention of cervical cancer, raising awareness to implement effective screening programs and decrease the number of cases. They are influential in encouraging individuals to seek care and have the expertise to educate them on the disease, its causes, risk factors, and screening options, ultimately impacting their screening behavior (23).

Globally, a substantial 40.0% of women were not aware that HPV is responsible for over 95 percent of cervical cancer cases. Among those uninformed about the HPV-cervical cancer link, a notable 39.1% had refrained from undergoing cervical cancer screening, surpassing the global average of 31.2% (1). Furthermore, 31.2% of individuals worldwide have never undergone cervical cancer screening. A large percentage (39.1%) of women who are unaware of the link between HPV and cervical cancer have never been screened for the disease, which is higher than the worldwide average (1). Specifically, Saudi Arabia (55.8%) and Serbia (36.5%) have the highest percentages of women who have never undergone cervical cancer screening. This discrepancy highlights an awareness gap that influences cervical cancer screening rates (1).

However, not all women undergo cervical cancer screening, with the highest risk being among those who have never been screened for cervical cancer till their diagnosis. Additionally, women without health insurance and recent immigrants are less likely to receive cervical cancer screening (24, 25). The rate at which individuals participate in cervical cancer screening can differ based on their understanding of the disease and screening options, as well as other factors like personal opinions, beliefs, attitudes, cultural influences, and the attitude of their partner (26). Previous studies in sub-Saharan Africa have shown that women face numerous obstacles in accessing cervical cancer screening services, including delayed diagnosis, weak health systems, limited funding, lack of information, high costs, societal and cultural beliefs, low awareness, and lack of clear government policies (27–29).

Around 90% of health workers in Turkey had positive attitudes toward cancer screening tests whereas practice-level screening methods were low, with only 4.2% performing pap smears (30). About 74.6% of women in South India had heard about cervical cancer whereas 76.9% knew about screening methods (31). More than half of the women (62.5%) have a positive attitude towards screening. More than three-fourths of women (349; 86.6%) do not have practice toward cervical cancer screening (31). A recent study conducted in Libya found that healthcare providers in health facilities were not adequately informing women about cervical cancer screening (32).

Although there were several studies conducted regarding knowledge, attitudes, and practice level towards cervical cancer screening among healthcare providers in Sub-Saharan Africa, there is a lack of consistent evidence regarding these healthcare providers' knowledge, attitudes, and practices. The magnitude of good knowledge, positive attitudes, and ever been practices regarding cervical cancer screening among healthcare providers in Sub-Saharan Africa varies significantly, with rates ranging from as low as 4.89% (33) to as high as 97.4% (34) for knowledge, 30.7% (35) to 97.4% (34) for attitudes, and 8.7% (35) to 72.6% (36) ever screened for cervical cancer. Thus, this review aimed to assess knowledge, attitudes, and practices related to cervical cancer screening among healthcare providers in Sub-Saharan Africa. It is crucial to regularly evaluate and address any gaps in their knowledge as having sufficient knowledge is vital for fostering positive attitudes and effective practices. Healthcare professionals are seen as examples to others and have the responsibility to educate the communities they work with about cervical cancer (37). The results of this study will be utilized by policymakers and program planners to enhance and assess cervical cancer screening services and strategies. The study also will provide baseline information for the future.

Materials and methods

Information sources and search strategy

Relevant databases include PubMed, Cochrane Library, AJOL, Google Scholar, and Science Direct. We searched articles from January 2013 and May 16, 2024, that were published in peer-reviewed journals or filed as completed dissertations with observational study design. We used a search strategy by combining the following key terms: knowledge, attitude, practice, cervical cancer, uterine cervical neoplasms, cervical cancer screening, health care provider, health professional, health personnel, health care workers, and Sub-Saharan Africa. We used both free texts, OR, AND, Boolean, and Medical subject heading [MeSH]terms in our search. Also, Gray literature of observational studies and official websites of international and local organizations and universities were searched. The study protocol was registered on PROSPERO, with the registration number CRD42023495241.

Study inclusion and exclusion criteria

This study included English-language research articles and doctoral dissertations conducted in Sub-Saharan Africa between January 2013 and May 16, 2024. The focus was on cross-sectional studies that examined the knowledge, attitude, and practice of healthcare providers toward cervical cancer screening. Only studies published in peer-reviewed journals or completed dissertations were considered. Our review included studies which assessed the knowledge, attitudes, and practices of various healthcare providers in sub-Saharan Africa towards cervical cancer screening, including physicians, nurses, midwives, anesthetists, pharmacy professionals, optometry professionals,

laboratory professionals, dentistry professionals, public health officers, and health extension workers. Studies that did not assess the knowledge, attitude, and practice of health care providers towards cervical cancer screening, as well as those conducted outside of Sub-Saharan Africa or not involving health professionals, were excluded. This study excluded case reports, case series, earlier reviews, and qualitative studies on cervical cancer screening uptake. Moreover, articles that were not fully accessible were excluded after attempting to contact the authors via email at least twice.

Data extraction and data quality assessment

After searching in relevant databases, the study was imported into Endnote version 20.6 and duplicates were removed. Then, three reviewers (AMD, EKB, and TFA) assessed the title and abstract to determine the eligibility of the article for full-text review. The full texts of the remaining papers were downloaded for further analysis, and full-text reviews were conducted. Finally, after applying inclusion and exclusion criteria, eligible studies were exported to Microsoft Excel version 2019 using a standardized data extraction checklist. Data were extracted using a standardized data extraction spreadsheet format prepared in Microsoft Excel. The data abstraction format includes the author/s name, year of publication, study area, study design, sample size, prevalence of knowledge, prevalence of attitude, and prevalence of cervical cancer practice.

The data quality was assessed using Joanna Briggs Institute's (JBI's) critical appraisal checklist for those included studies. Three authors (ETF, DE, and MGT) independently assessed the quality of each article. Whenever necessary, another reviewer (AAT) was involved and any discrepancy was resolved through discussion and consensus. In conclusion, studies that scored 6 or higher out of 9 were classified as being of high quality (38). The studies included in the analysis had quality scores ranging from 6 to 9. Besides, studies that had methodological flaws, incomplete reporting of results; or those for which full text was not available were excluded from the final analysis. Study researchers made two separate attempts to contact article authors whenever additional study information was needed (Table 1).

Data processing and analysis

Data from Microsoft Excel was transferred to STATA software version 17 for further statistical analysis. The heterogeneity of the study results was evaluated using Cochrane's Q statistics, and I^2 statistics (39). The results were presented using a forest plot, tables, and graphs. The test results showed significant heterogeneity, so we used a random-effect meta-analysis model to determine the overall knowledge status, attitude, and practice level. Subgroup analyses were conducted based on geographical region to address the possible source of heterogeneity. We also employed various statistical tests, including funnel plot asymmetry, Egger's test, and Begg's test, to examine the presence of publication bias (40). Visual

TABLE 1 Methodological quality assessment of included studies using the JBI critical appraisal checklist for prevalence studies.

Author	Was the sample frame appropriate to address the target population?	Were study participants sampled appropriately?	Was the sample size adequate?	Were the study subjects and the setting described in detail?	Was the data analysis conducted with sufficient coverage of the identified sample?	Were valid methods used for the identification of the condition?	Was the condition measured in a standard, reliable way for all participants?	Was appropriate statistical analysis used?	Was the response rate adequate, and if not, was the low response rate managed appropriately?	Total score
Oche, MO	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Ugwu, E. O.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	8
Anyebe, EE	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	7
Kieti, S	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	6
Gebreegziabher, M	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Addissie, A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Aseres, T	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Dulla, D	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9

(Continued)

TABLE 1 Continued

Author	Was the sample frame appropriate to address the target population?	Were study participants sampled appropriately?	Was the sample size adequate?	Were the study subjects and the setting described in detail?	Was the data analysis conducted with sufficient coverage of the identified sample?	Were valid methods used for the identification of the condition?	Was the condition measured in a standard, reliable way for all participants?	Was appropriate statistical analysis used?	Was the response rate adequate, and if not, was the low response rate managed appropriately?	Total score
Ziwu, R	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	8
Niyonzimaj, P	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	8
Shayo F	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	8
Ndizeye, Z	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	8
Ifemelumma, CC	Yes	Yes	No	No	Yes	No	No	Yes	Yes	7
Getahun, F	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	7
Mwale, S	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	8
Ogunsuyi, G	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	7
Odenusi, AO	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Omotunde O.	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	7
Ararsa, T	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Obol, J	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Melese B	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Olarinoye, AO	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	6
Theophil, T	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Abebaw, E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Logbo-Akey, K	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	6
Chitha, W	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Jegede S	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	7
Berhanu, T	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	8
Mathivha, L	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Nyaaba, J	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9

Operational definition
Knowledge: Refers to health care providers' awareness towards cervical cancer screening in Sub-Saharan Africa.
Attitude: Refers to the way of thinking or feeling of health care providers towards cervical cancer screening.
Practice (P). Refers to every screening status of female health care workers for cervical cancer.
Healthcare Providers: All healthcare workers in Sub-Saharan Africa (physicians, Nurses, Midwives, Anesthetists, Pharmacy professionals, Optometry professionals, Laboratory professionals, Dentistry professionals, Public health officers, and health extension workers).

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inspection of funnel plots can help identify publication bias, but it is not enough to rely solely on subjective interpretations (41). It is recommended to use additional statistical tests, such as Egger's test (42) and Begg's test (43), to more accurately assess the presence and severity of publication bias. Both meta-regression and, nonparametric trim and fill analysis were carried out to detect the source of publication bias and to adjust the pooled magnitude of attitude and practice of health providers respectively. The researchers also conducted sensitivity analyses to determine how each study affected the overall findings on knowledge, attitude, and practice toward cervical cancer screening. They did this by excluding one study at a time.

Results

Selection of eligible studies

This systematic review and meta-analysis have been reported by the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statements. Initially, 1264 articles related to knowledge, attitude, and practice towards cervical cancer screening were found. Of these, 935 duplicates and 281 articles by title and abstract were removed. After a thorough review, 18 articles were deemed irrelevant and excluded from the analysis. Ultimately, 30 articles were found to be suitable for the review and were included in the analysis (Figure 1).

Characteristics of included studies

A total of 30 studies with a total sample of 7542 healthcare providers were included in this systematic review and meta-analysis. All the studies in this review were conducted using a cross-sectional study design and were published between 2013 and 2023. Among the 30 studies included, 14 were carried out in Eastern Africa (35, 44–56), 12 studies in Western Africa (23, 34, 57–66), and 4 studies in Southern Africa (67–70). Out of the total number of studies, 7 included both male and female participants (45, 51, 52, 54, 67, 69, 71), while 23 studies only included female healthcare Providers. The pooled magnitude of knowledge status towards cervical cancer screening was determined using 15 studies (34, 35,

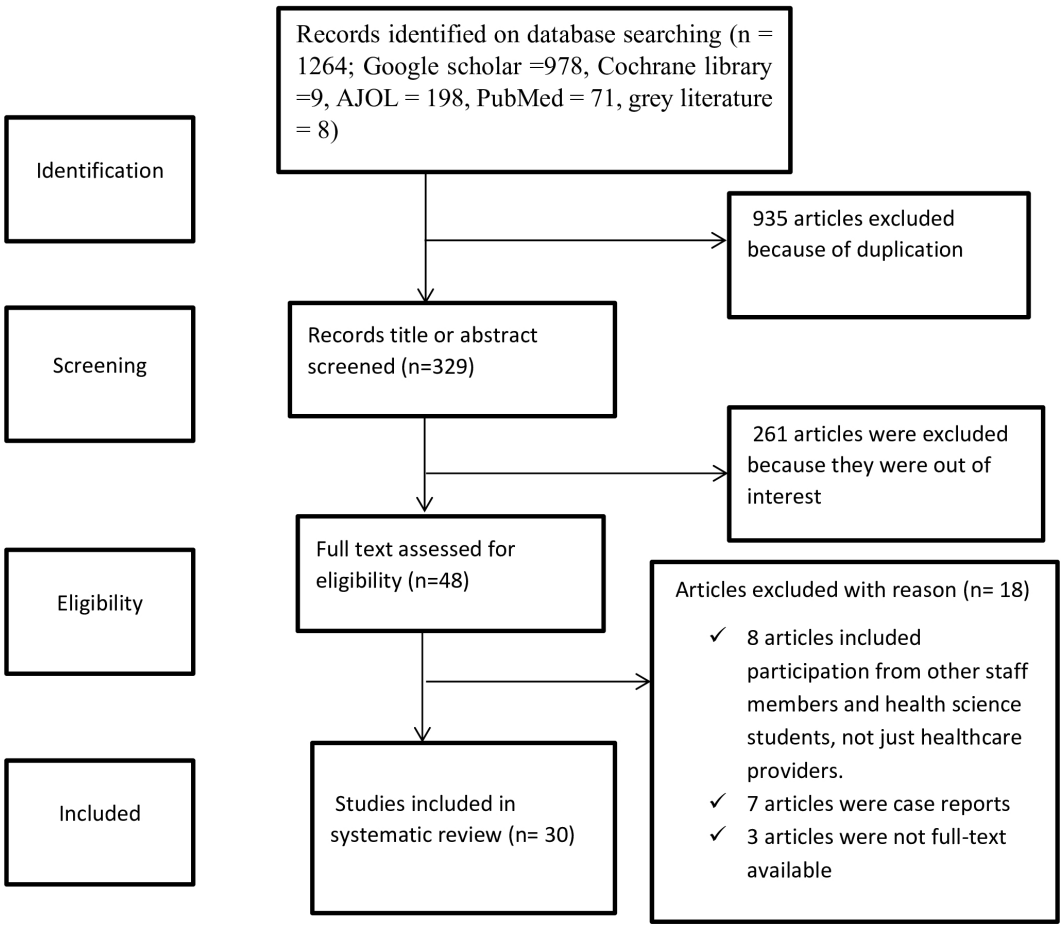

FIGURE 1
PRISMA flow diagram of knowledge, attitude and practice towards cervical cancer screening among health care providers in Sub-Saharan Africa, 2023.

46–50, 52, 59–61, 64–66, 69), while the pooled magnitude of attitude towards cervical cancer screening was assessed using 9 studies (34, 35, 47–50, 64, 66, 67). Additionally, 23 studies (23, 34, 35, 45–49, 53–60, 62, 64–66, 68–70) were used to assess the pooled magnitude of practice to ever screened status towards cervical cancer among female healthcare providers in Sub-Saharan Africa. Two studies (51, 71) did not provide the pooled results but instead reported on knowledge status regarding various screening methods such as pap smear, VIA, VILI, colposcopy, and HPV DNA test. Out of the total studies reviewed, 9 were unpublished (46, 49, 52, 53, 56, 58, 64, 67, 70) and the remaining 21 of them were published research (Table 2).

Pooled magnitude of knowledge and attitude status of health care providers towards cervical cancer

This study assessed the level of knowledge and attitude toward cervical cancer among healthcare providers in Sub-Saharan Africa. Accordingly, the pooled level of good knowledge status about cervical cancer based on 9 included studies (48, 52–55, 57, 59, 60, 71) in Sub-Saharan Africa was 67.93% (95% CI: 53.36–82.50) (Figure 2). Moreover, the pooled magnitude of positive attitude of health care providers towards cervical cancer based on 2 included studies (52, 54) in Sub-Saharan Africa was 55.26% (95% CI: 34.28– 76.23) (Figure 3).

TABLE 2 Characteristics of the included studies in meta analysis for knowledge, attitude and practice of healthcare providers towards cervical cancer screening in Sub Saharan Africa, 2023.

Sn	Author	Year	Country	Study Design	Study Population	SS	Knowledge	Attitude	SS For practice	Practice (ever screened)
1.	Oche, MO	2013	Nigeria	CS	FHCW	220	NA	NA	220	10
2.	Ugwu, E. O.	2013	Nigeria	CS	FHCW	177	91	NA	177	14.1
3.	Anyebe, EE	2014	Nigeria	CS	Female nurses	117	97.4	97.4	117	15
4.	Kieti, S	2016	Kenya	CS	FHCW	114	90.35	NA	114	56
5.	Gebreegziabher, M	2016	Ethiopia	CS	Female nurses	225	4.89	63.11	225	10.7
6.	ADDISSIE, A	2016	Ethiopia	CS	FHCW	417	15.9	NA	NA	NA
7.	Aseres, T	2017	Ethiopia	CS	FHCW	322	NA	NA	322	18.3
8.	Dulla, D	2017	Ethiopia	CS	FHCW	367	NA	NA	367	11.4
9.	Ziwu, R	2017	Ghana	CS	FHCW	171	NA	NA	171	16.47
10.	NiyonzimaJ, P	2018	Rwanda	CS	Nurses & midwives	527	NA	NA	464	32.9
11.	Shayo F	2018	Namibia	CS	doctors & Nurses	151	NA	93.4	NA	NA
12.	Ndizeye, Z	2018	Burundi	CS	general practitioners	131	NA	NA	NA	NA
13.	Ifemelumma, CC	2019	Nigeria	CS	female nurses	388	NA	NA	388	20.6
14.	Getahun, F	2019	Ethiopia	CS	HCW	309	NA	NA	NA	NA
15.	MWALE, S	2020	Zambia	CS	female nurses	50	NA	NA	50	25
16.	Ogunsuyi, G	2020	Nigeria	CS	PHCW	192	13	NA	192	NA
17.	Odenusi, AO	2020	Nigeria	CS	FHCW	261	98.4	NA	261	23.2
18.	Omotunde O	2020	Nigeria	CS	Female nurses	407	58.8	48.4	407	23.3
19.	Ararsa, T	2021	Ethiopia	CS	urban HEW	312	48.4	46.8	NA	NA
20.	Obol, J	2021	Uganda	CS	HCW	286	NA	NA	188	75
21.	Melese B	2021	Ethiopia	CS	FHCW	258	21	98.1	258	14.7
22.	Olarinoye, AO	2021	Nigeria	CS	FHCW	348	30.2	NA	348	20.4
23.	Theophil, T	2022	Tanzania	CS	female doctors & nurses	221	NA	NA	221	29.9

(Continued)

TABLE 2 Continued

Sn	Author	Year	Country	Study Design	Study Population	SS	Knowledge	Attitude	SS For practice	Practice (ever screened)
24.	Abebaw, E.	2022	Ethiopia	CS	FHCW	404	43.8	30.7	404	8.7
25.	Logbo-Akey, K	2022	Togo	CS	Midwives	50	NA	NA	50	NA
26.	Chitha, W	2023	South Africa	CS	Nurses	119	20.8	NA	106	72.6
27.	Jegede S	2019	Nigeria	CS	FHCW	176	62.4	69.6	176	40
28.	Berhanu, T	2019	Ethiopia	CS	HEW	291	48.5	51.5	291	54
29.	Mathivha, L	2023	South Africa	CS	female nurses	264	NA	NA	264	83
30.	Nyaaba, J	2023	Ghana	CS	FHCW	267	NA	NA	267	35.11

FHCW, Female Health Care Workers; CS, Cross-sectional; HCW, Health Care Workers; HEW, Health Extension Workers; NA, Not Available; PHCW, Primary Health Care Workers; SS, Sample Size.

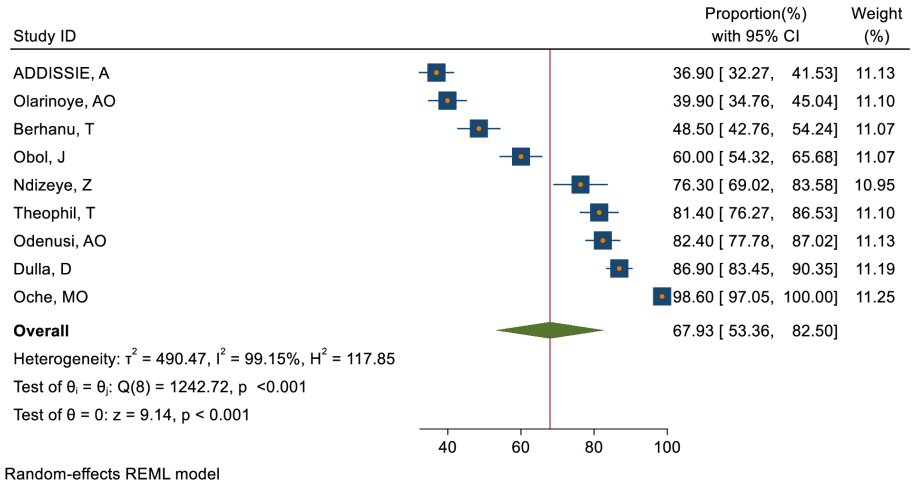

FIGURE 2
Overall magnitude of goods knowledge status of healthcare providers towards cervical cancer in Sub-Saharan Africa, 2023.

Overall knowledge status of health care providers regarding causes, risk factors, signs and symptoms, outcomes, and prevention methods of cervical cancer

Healthcare providers have a good knowledge status of 42.51% regarding the causes of cervical cancer, 73.51% regarding the risk factors, 76.85% regarding the symptoms, 81.7% regarding the outcomes, and 72.75% regarding the prevention methods (Figure 4).

Knowledge status of health care providers towards risk factors of cervical cancer

About 66.38%, 52.47%, 52.06% and 50.46% of healthcare providers know HPV infection, HIV, early sexual intercourse, and STI mention as a risk factor for cervical cancer respectively. In contrast, about 1.98% do not mention any of the risk factors (Figure 5).

Knowledge status of health care providers regarding signs and symptoms of cervical cancer

Around 65.56%, 60.99%, 56.93%, and 54.55% of healthcare providers were aware of postcoital bleeding, abnormal menstruation, bleeding during sexual intercourse, and foul-smelling vaginal discharge as potential signs and symptoms of cervical cancer. Less than half of healthcare providers are knowledgeable about certain symptoms and conditions, such as painful sexual intercourse (47.5%), postmenopausal bleeding (41.73%), pelvic or back pain (39.16%), and contact bleeding (23.96%). A small percentage (4.62%) do not know any of the

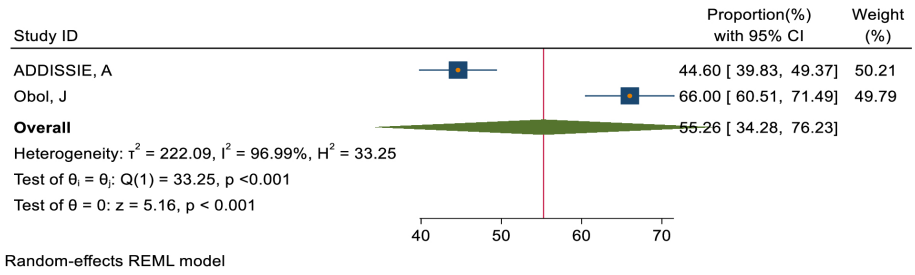

FIGURE 3
Overall magnitude of positive attitude status of healthcare providers towards cervical cancer in Sub-Saharan African, 2023.

signs and symptoms, while an even smaller percentage (2.3%) are unaware of weight loss as a potential symptom (Figure 6).

The overall magnitude of knowledge, attitude, and practice status toward cervical cancer screening

This study assessed knowledge status, attitude, and practice toward cervical cancer screening among healthcare providers in Sub-Saharan Africa. The pooled level of good knowledge towards cervical cancer screening was 49.68% (95% CI: 33.18–66.17) (Figure 7) whereas the pooled magnitude of positive attitude toward cervical cancer screening among healthcare providers in Sub-Saharan Africa was 66.63% (95% CI: 50.36– 82.89) (Figure 8). On the other hand, the pooled magnitude of ever screened for cervical cancer among female healthcare providers in Sub-Saharan Africa was 30.78% (95% CI: 21.69–39.88) (Figure 9). Since this result had a significant publication bias, the true pooled magnitude of female healthcare providers ever screened for cervical cancer was found to be 17.23% (95% CI; 6.08-28.37) after accounting for publication bias through trim and fill analysis.

Subgroup analysis

Subgroup analysis was carried out based on geographical regions. Accordingly, the pooled magnitude of knowledge status towards cervical cancer screening among healthcare providers was 38.92% (95% CI: 17.83– 60.01) in East Africa, 64.50%(95% CI: 39.54–89.47) in Western Africa, and 20.80%(95% CI: 13.51– 28.09) in Southern Africa respectively (Figure 10). Similarly, the pooled magnitude of

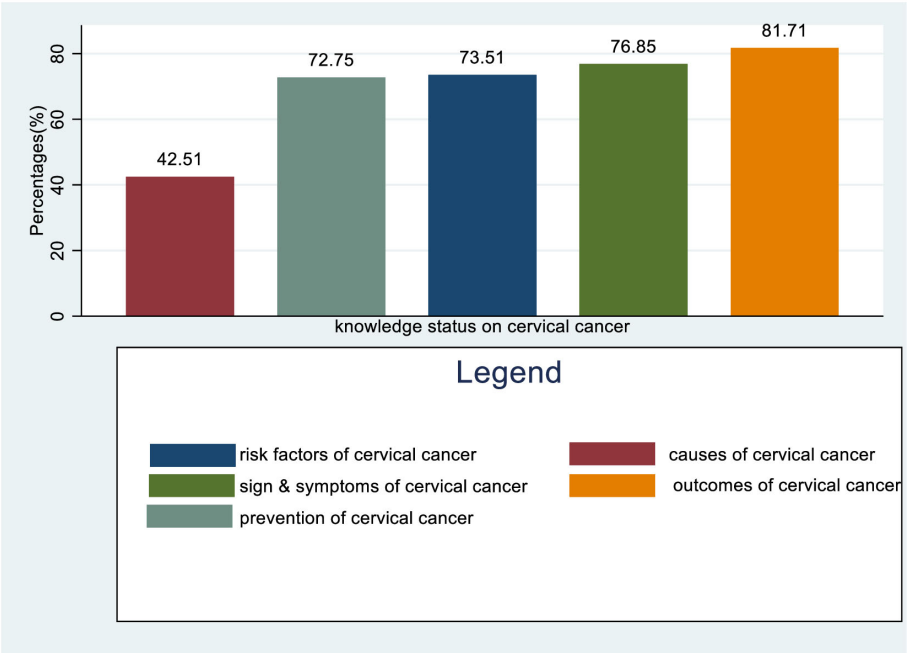

FIGURE 4
Overall Knowledge status of healthcare providers towards causes, risk factors, symptoms, outcome, and prevention methods of cervical cancer in Sub-Saharan Africa, 2023.

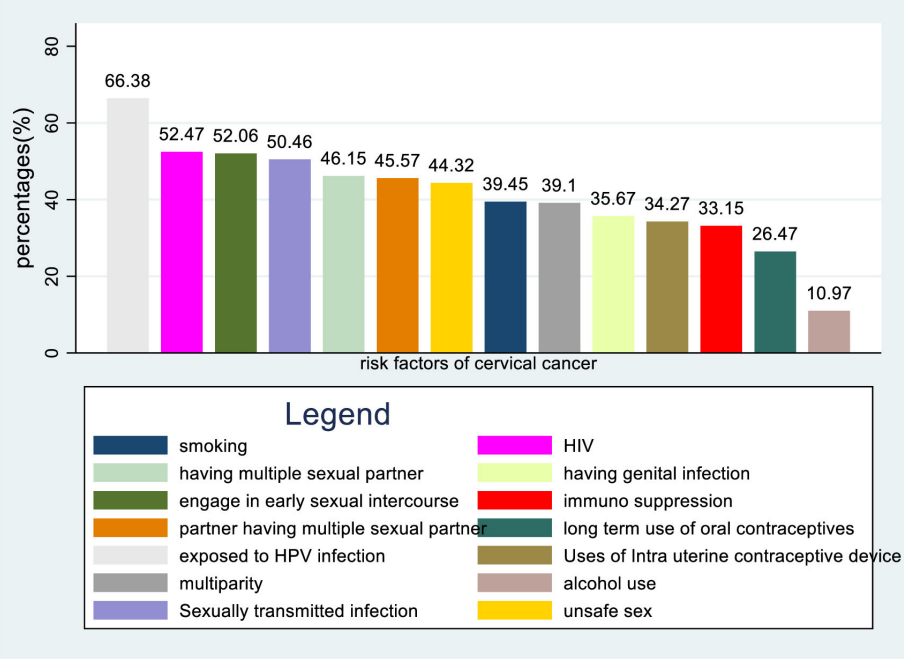

FIGURE 5
Bar graph for knowledge status of healthcare providers towards risk factors of cervical cancer in Sub-Sahara Africa, 2023.

positive attitudes toward cervical cancer screening among healthcare providers was 58.11%(95% CI: 35.85– 80.36) in East Africa, 71.86% (95% CI: 43.93-99.80) in Western Africa, and 93.40%(95% CI: 89.44–97.36) in Southern Africa respectively (Figure 11). Besides, the pooled magnitude of healthcare providers ever screened for cervical cancer was 31.00%(95% CI: 16.71– 45.30) in East Africa, 21.64%(95% CI: 16.01–27.27) in Western Africa, and 60.54%(95% CI: 25.80– 95.28) in Southern Africa respectively (Figure 12).

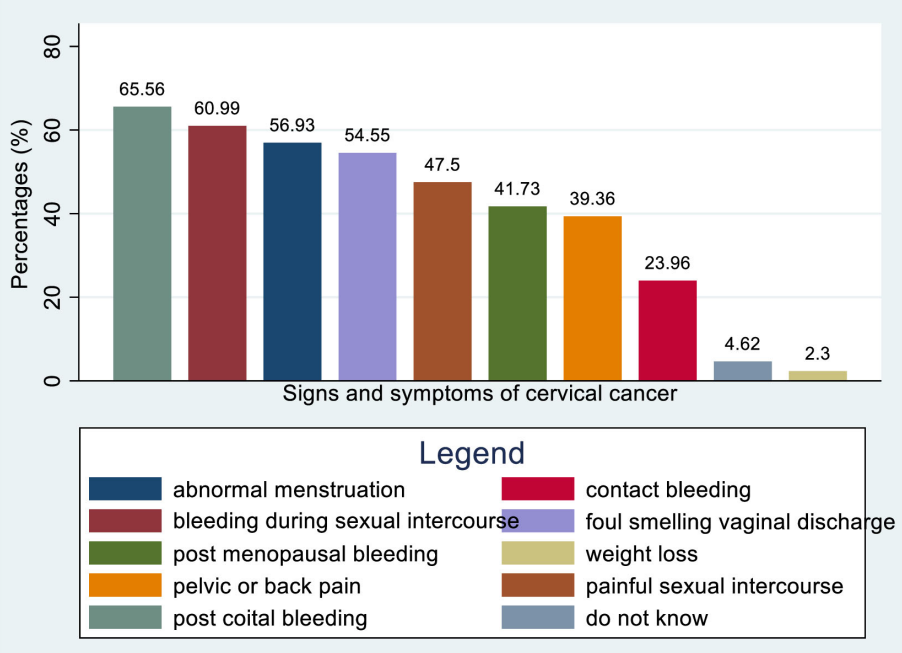

FIGURE 6
Bar graph for knowledge status of healthcare providers towards symptoms and signs of cervical cancer in Sub-Sahara Africa, 2023.

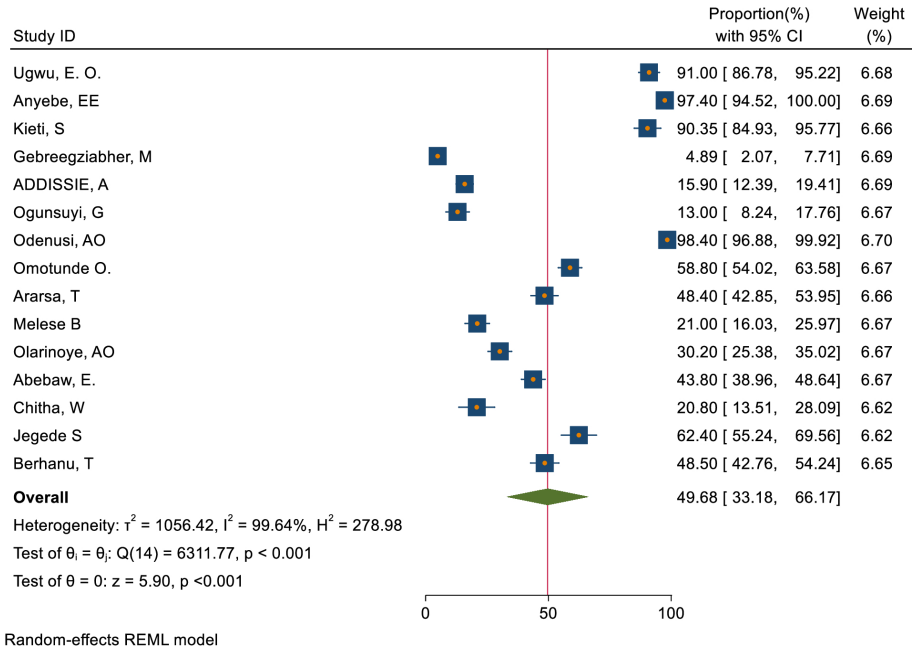

FIGURE 7
Overall magnitude of good knowledge status of health care providers towards cervical cancer screening in Sub-Saharan Africa, 2023.

Knowledge status of healthcare providers towards cervical cancer screening methods and regular cervical cancer screening interval

Around 72.02% of healthcare providers knew about pap smear as a screening method for cervical cancer, while 46.15% were aware of the HPV DNA test. Furthermore, approximately 41.68% knew about both pap smear and VIA, while 35.54% were only aware of VIA. A total of 30.18% were aware of VILI, and 23.92% knew about either VIA or VILI as screening methods for cervical cancer (Figure 13). The overall knowledge status towards knowing the regular interval for cervical cancer screening was 27.34% (95% CI: 18.93– 35.76) (Figure 14).

Reasons for not being screened yet for cervical cancer

A variety of reasons were given by respondents for not being screened. Approximately 28.47% of respondents chose not to get screened because they believed they were healthy. Another 27.97%

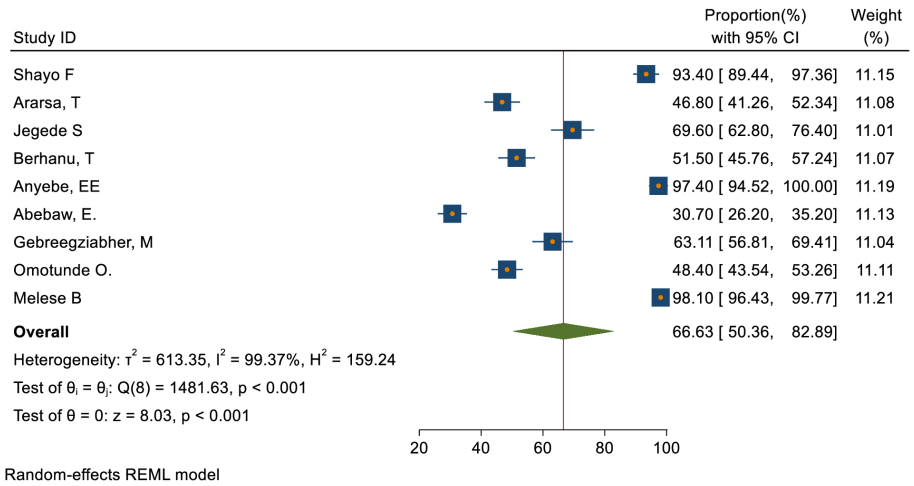

FIGURE 8
Overall magnitude of positive attitude of healthcare providers towards cervical cancer screening in Sub-Saharan Africa, 2023.

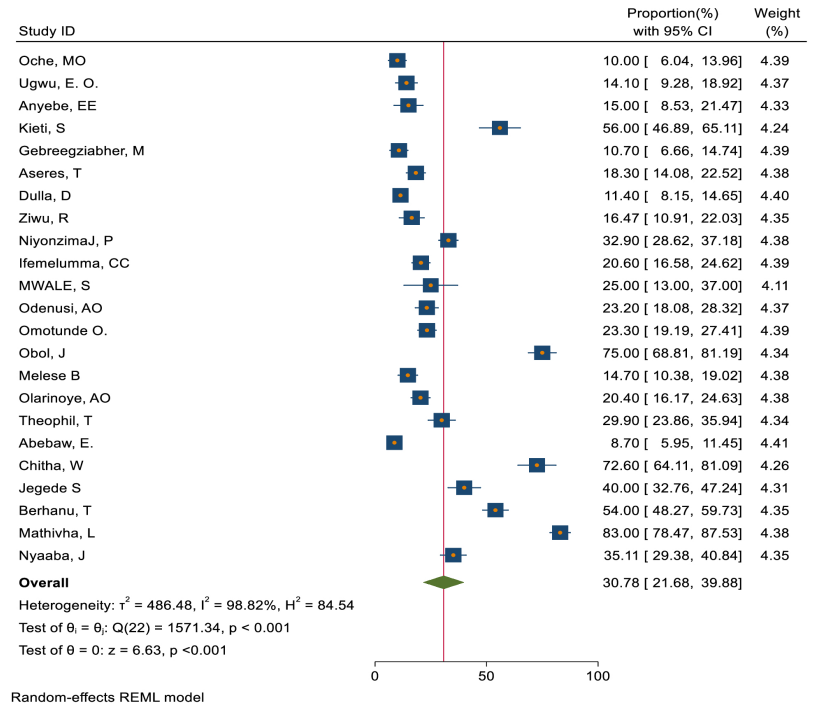

FIGURE 9
Overall magnitude of practice to ever screened for cervical cancer screening among female healthcare providers in Sub-Saharan Africa, 2023.

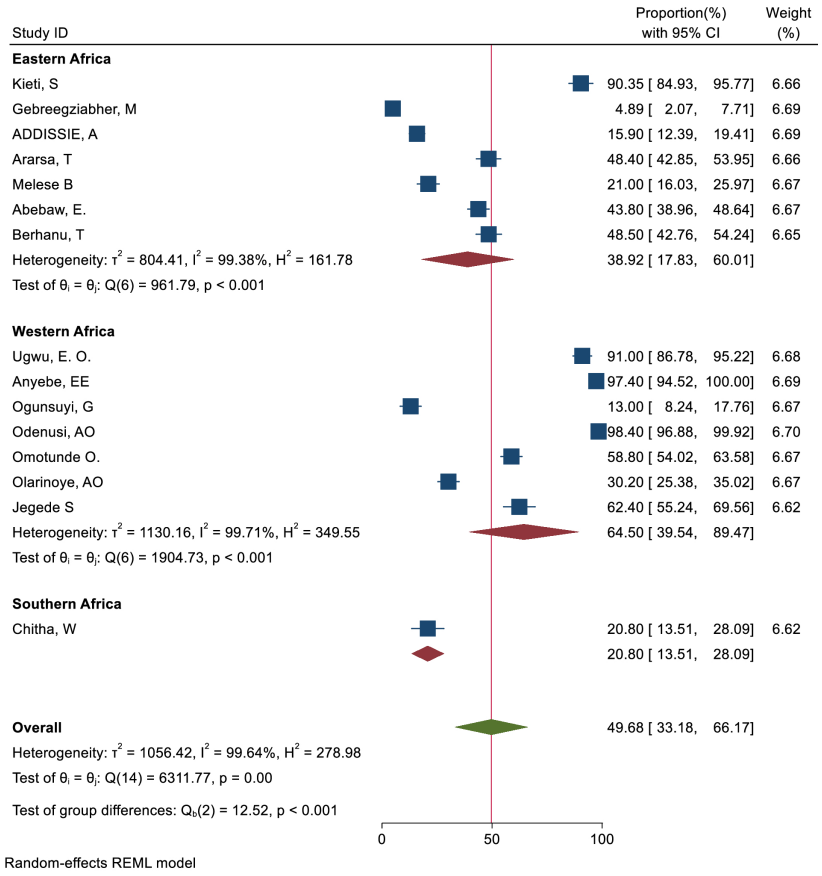

FIGURE 10
Subgroup analysis-based study area of knowledge status towards cervical cancer screening among health care providers in Sub-Sahara Africa, 2023.

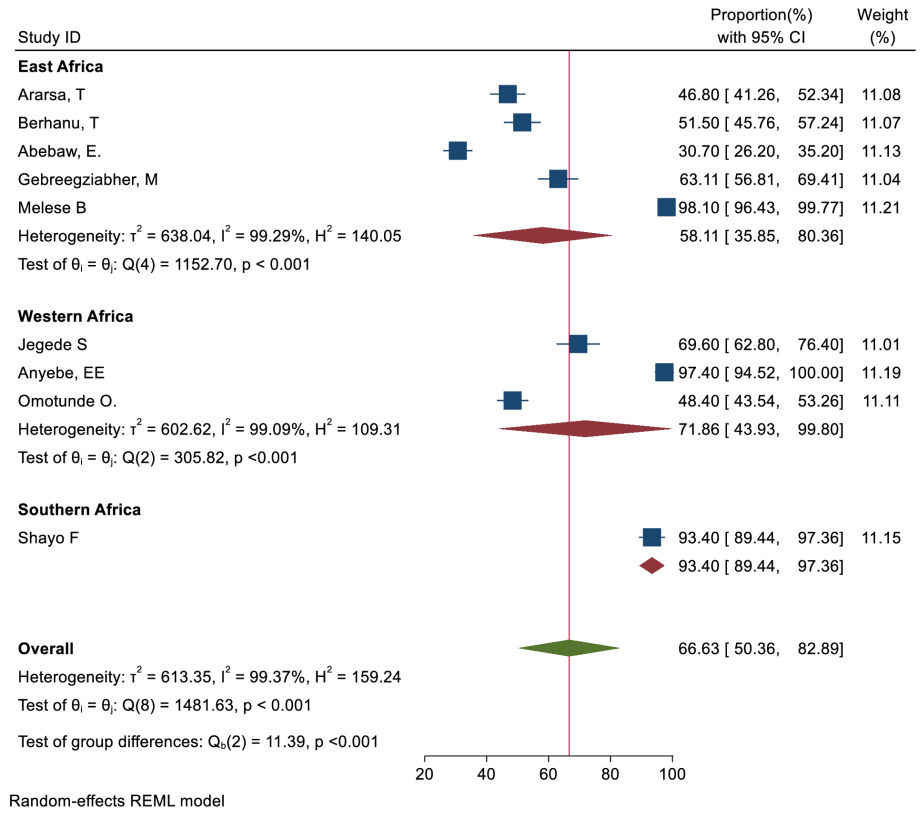

FIGURE 11
Sub group analysis-based study area of attitude status towards cervical cancer screening among healthcare providers in Sub Sahara Africa, 2023.

were afraid of receiving a positive result, while 25.82% were afraid of experiencing pain during the screening. Additionally, 24.38% cited privacy concerns, 22.68% mentioned the cost of screening as a deterrent, 22.28% believed they were not susceptible to the condition being screened for, and 21.62% stated that the service was inaccessible. On the other hand, 19.42% of respondents were not screened due to their husband's disapproval, 16.66% cited a lack of time, and 16.02% expressed no interest or carelessness. Other reasons included fear of using rusty or dirty equipment (15.9%), being considered too old for screening (14.74%), cultural or religious beliefs (8.22%), and fear of embarrassment (4.29%) (Figure 15).

Publication bias assessment and sensitivity analysis

The researchers checked for publication bias by visually inspecting a funnel plot, as well as using statistical tests. The funnel plot showed that the included studies were distributed symmetrically. Moreover, both Begg's and Egger's tests indicated the absence of publication bias in the knowledge status of healthcare providers towards cervical cancer screening. The tests showed no statistical evidence of publication bias with a p-value greater than 0.05 (P value; Eggers test=0.38, Beggs test=1.00), and the funnel plot was symmetrical (Figure 16). On the contrary, the study found that there was publication bias in the data on healthcare providers' attitudes towards cervical cancer screening. The funnel plot revealed an uneven distribution of the studies (Figure 17). The Egger's test found evidence of publication bias (P value=0.04), indicating that there may be a bias in the published studies. However, Begg's test (P value=0.60) suggested that there is no publication bias regarding the attitude of healthcare providers towards cervical cancer screening. To address this bias, the researchers conducted a trim and fill analysis however the pooled magnitude of attitude did not impute additional studies and the overall magnitude of attitude did not vary from the original findings.

We also assessed publication bias for the practice of female healthcare providers to ever screened for cervical cancer. Accordingly, Egger's tests indicated the absence of publication bias in the pooled magnitude healthcare providers ever screened for cervical cancer (P value; Eggers test=0.10). However, Beggs tests showed statistical evidence of publication bias with a p-value less than 0.05(P value; Beggs test=0.04), and the funnel plot was asymmetrical (Figure 18). To address this bias, the researchers conducted a trim and fill analysis, which adjusted the original pooled results of 30.80%(95% CI: 21.69–39.91). The adjusted pooled magnitude of healthcare providers ever screened for cervical cancer was 17.23 (95% CI; 6.08-28.37) after including eight additional studies on the left side. This adjusted result is considered to be a more accurate representation of the true practice

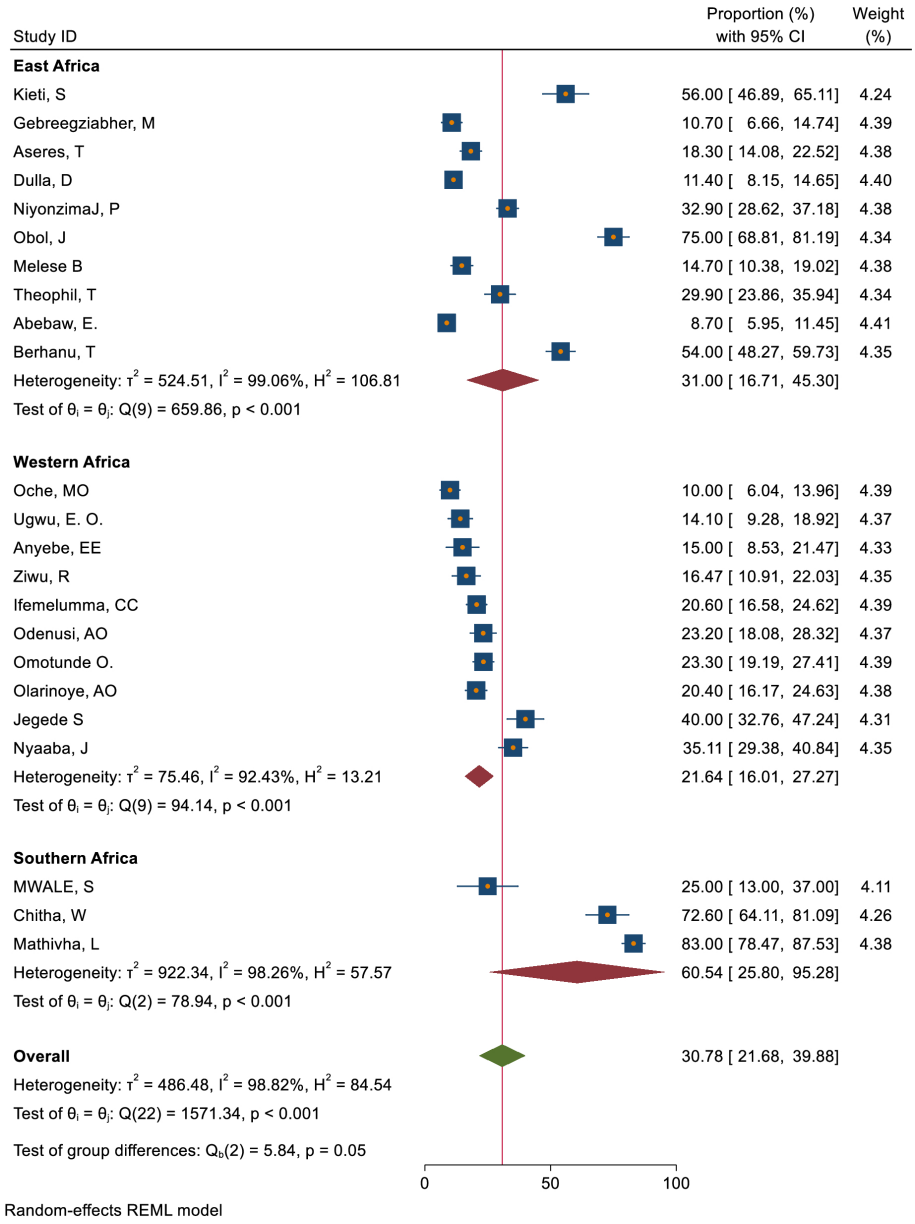

FIGURE 12
Sub group analysis-based on study area practices to ever screen for cervical cancer among healthcare providerd in Sub Sahara Africa, 2023.

of healthcare providers ever screened for cervical cancer. The result of sensitivity analyses revealed that none of the studies included influenced the overall estimate (Figures 19–21).

Meta-regression

Besides, trim and fill analysis for publication bias, meta-regression analysis was performed by considering sample size and publication year for the included studies to identify sources of bias for the pooled prevalence. We included a total of 9 studies (34, 35, 47–50, 64, 66, 67) for attitude towards cervical cancer screening and 23 studies (23, 34, 35, 45–49, 53–60, 62, 64–66, 68–70) for the practice of ever being screened for cervical cancer in our meta-regression analysis. In this analysis, the sample size was a statistically significant source of publication bias for the pooled magnitude of attitude status whereas publication year is the source of publication bias for health care providers' practice to ever screen for cervical cancer as shown in the values from the meta-regression analysis (Table 3).

Discussion

The World Health Assembly aimed to reduce cervical cancer through a 90-70-90 policy, but healthcare providers in sub-Saharan Africa had significant gaps in their knowledge, attitude, and practice towards cervical cancer and its screening. The results of this meta-

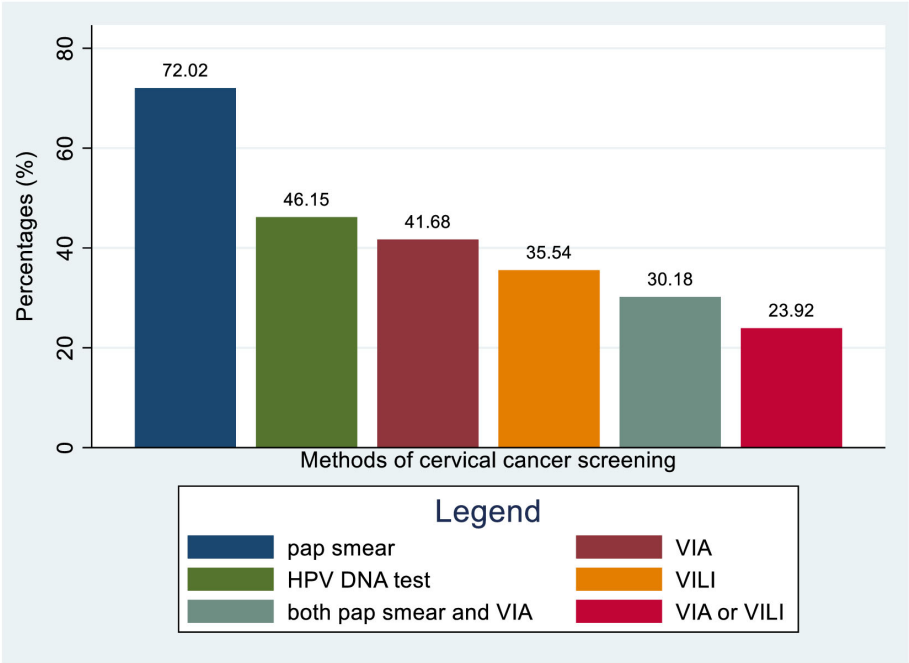

FIGURE 13
Bar graph for knowledge status of healthcare providers towards different cervical cancer screening methods in Sub-Sahara Africa, 2023.

analysis showed that the pooled magnitude of good knowledge status and positive attitude of healthcare providers towards cervical cancer was 67.93% (95% CI: 53.36–82.50) and 55.26% (95% CI: 34.28–76.23)respectively. This implied that healthcare providers do not have adequate knowledge and a positive attitude towards cervical cancer. This pooled magnitude of knowledge was consistent with 80% in Saudi Arabia (72) and 75.15% in India (73) and it was lower as compared to 92% in Pakistan (74). On the other hand, the pooled magnitude of positive attitudes towards cervical cancer screening was lower as compared to 78% in Pakistan (74). The possible explanation for these discrepancy in the magnitude of knowledge and attitudes towards cervical cancer could results from variations in training, workload, resource limitations, and cultural beliefs within the specific environments

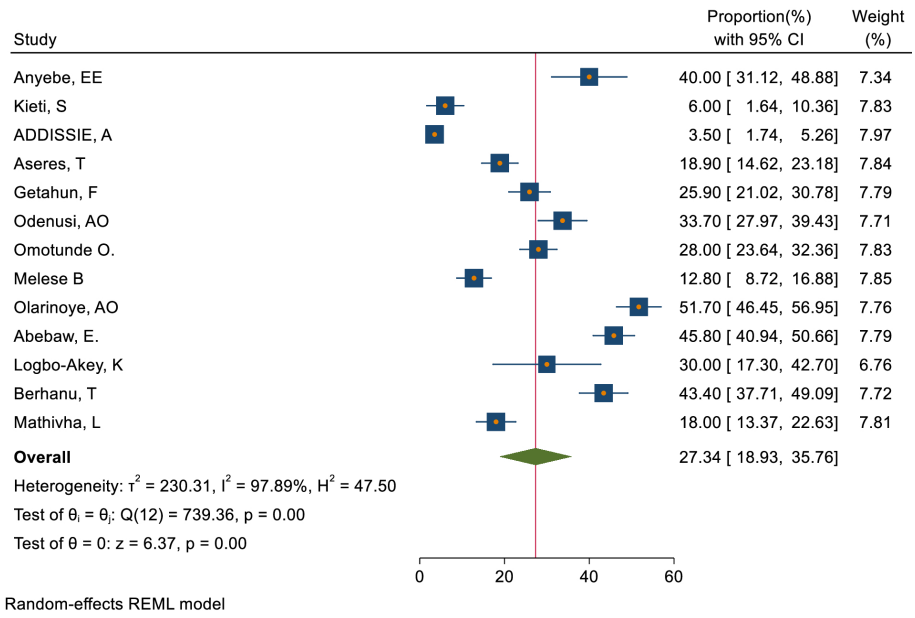

FIGURE 14
Overall knowledge status of healthcare providers towards knowing the regular interval for cervical cancer screening in Sub-Sahara Africa, 2023.

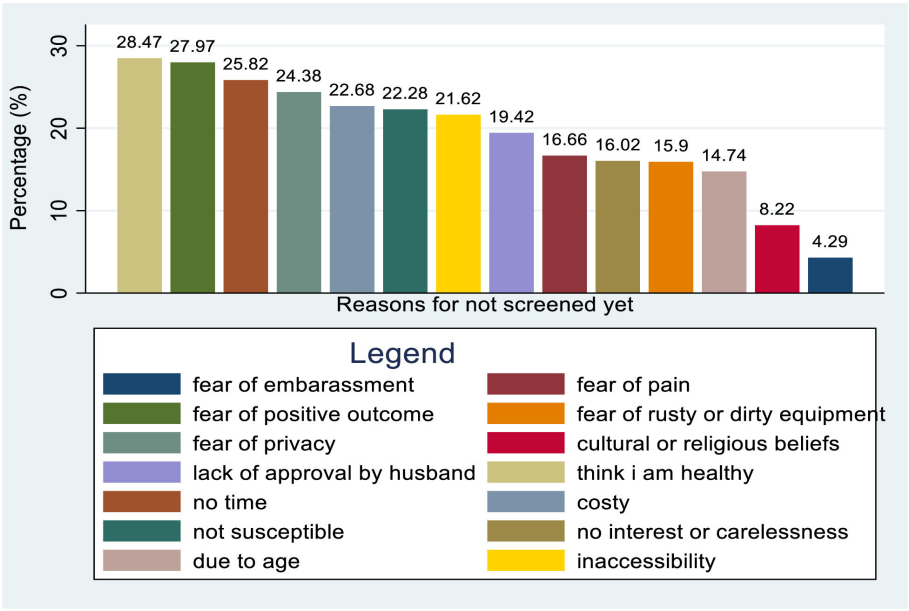

FIGURE 15
Bar graph indicating reasons for not screened yet for cervical cancer of health care providers towards risk factors of cervical cancer in Sub Sahara Africa, 2023.

being studied. These factors may contribute to the observed differences in understanding and behaviors among individuals.

This review also found that the overall level of good knowledge, positive attitude, and practice of cervical cancer screening among healthcare providers was 49.68% (95% CI: 33.18–66.17), 66.3% (95% CI: 50.36–82.89), and 30.785% (95% CI: 21.68–39.88), respectively. The statement suggests that healthcare providers in sub-Saharan Africa have limited knowledge, attitude, and practice towards cervical cancer screening despite the fact that they are expected to serve as examples for eligible women who should undergo such screening. The overall magnitude of knowledge status towards cervical cancer screening was consistent with overall knowledge of 60.4% in Egypt (75) and 56.3% in China (76). However, it was lower as compared to 86.2% in India (73). Moreover, the overall magnitude of positive attitude status towards cervical cancer screening was also consistent with 53.4% in Egypt (75) but it was lower as compared to 85.47% in India (73) and 90% in

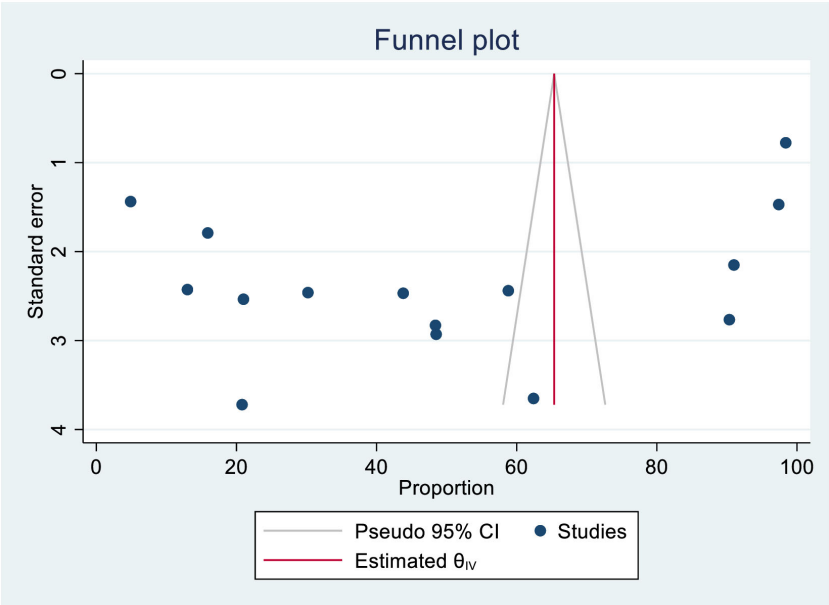

FIGURE 16
Funnel plot assessment for knowledge status towards cervical cancer screening among healthcare providers in Sub Saharan Africa, 2023.

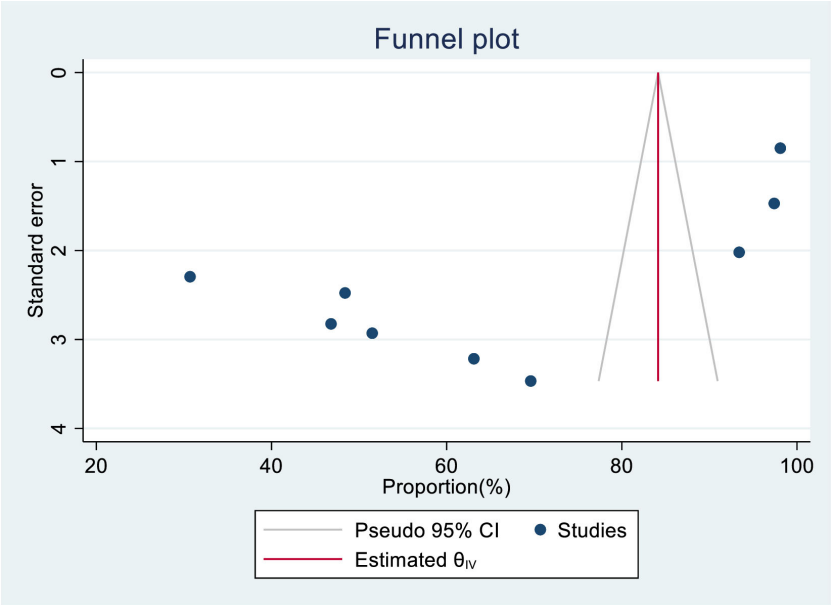

FIGURE 17
Funnel plot assessment for attitude status towards cervical cancer screening among health care providers in Sub Saharan Africa, 2023.

Turkey (30). This discrepancy in healthcare providers' knowledge and attitude towards cervical cancer screening could be attributed to differences in their specialization, experiences, and professional competency levels of health professionals included in their sample. These differences may also be influenced by variations in training and education provided to healthcare professionals in different countries. The limited access to screening services and lack of emphasis on cervical cancer screening in the study location may contribute to this discrepancy, which could be further influenced by variations in access to screening services and information dissemination.

The findings of this study regarding the overall practice of female healthcare providers who had been screened for cervical cancer in Sub-Saharan Africa was consistent with 12.7% in India (73), 26.2% in Saudi Arabia (77), and 26.6% in Sri Lankan (78). The result was not significantly different from a systematic review and meta-analysis conducted on women of reproductive age in

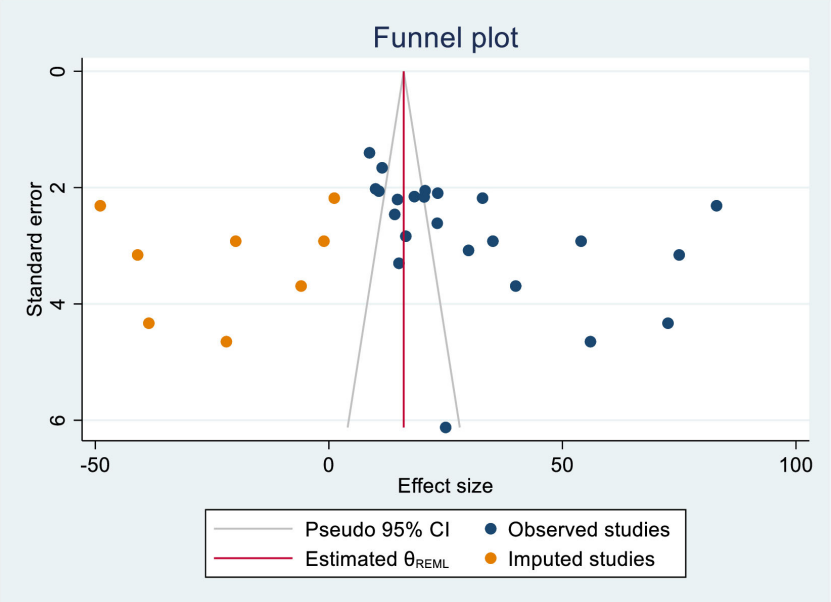

FIGURE 18
Funnel plot assessment of practice for female healthcare providers to ever screened status towards cervical cancer screening in Sub Saharan Africa, 2023.

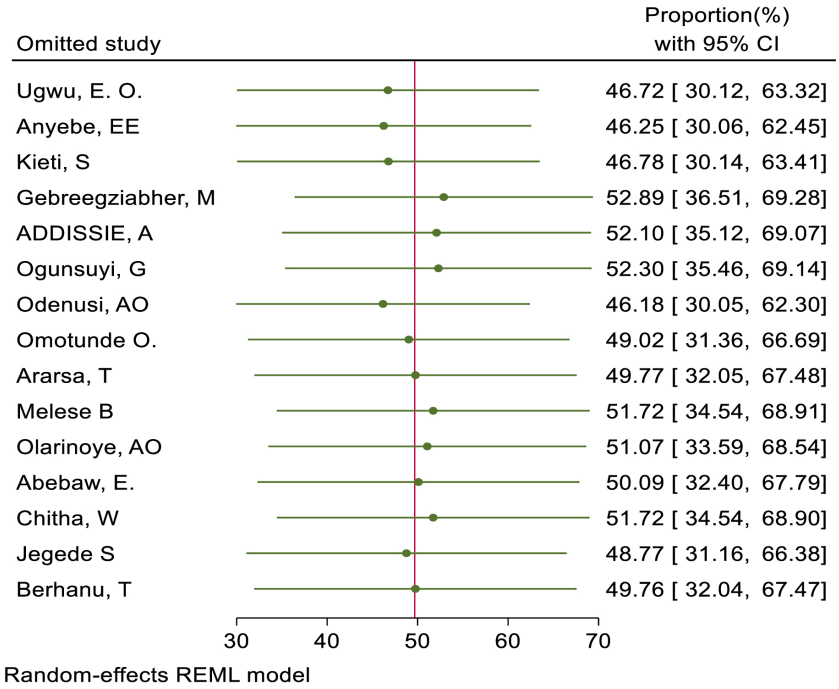

FIGURE 19
Sensitivity analysis for good knowledge status of health care providers towards cervical cancer screening among health care providers in Sub Saharan Africa, 2023.

Sub-Saharan Africa, where the percentage was 12.87% (79). But it was lower as compared with 42.2% in Qatar (80) and 45.2% in south Turkey (81). This variation might be justified by the extent of the studies and differences in the health service, sociodemographic characteristics of study participants, and setting and study period.

Female healthcare providers reported various reasons for not being screened for cervical cancer, including fear of embarrassment, fear of pain, lack of time, fear of positive outcomes, fear of privacy, lack of availability of services, carelessness, fear of using dirty or rusty equipment, lack of approval from their husbands, cultural and religious beliefs, thinking they are not susceptible to the disease, high costs, feeling healthy, and lack of access to services. This suggests that individuals who perceive themselves as healthy often overlook preventive services, and a lack of awareness about cervical cancer screening contributes to low utilization of these services. This finding was supported by a previous study conducted in India (82) and in Korea (83).

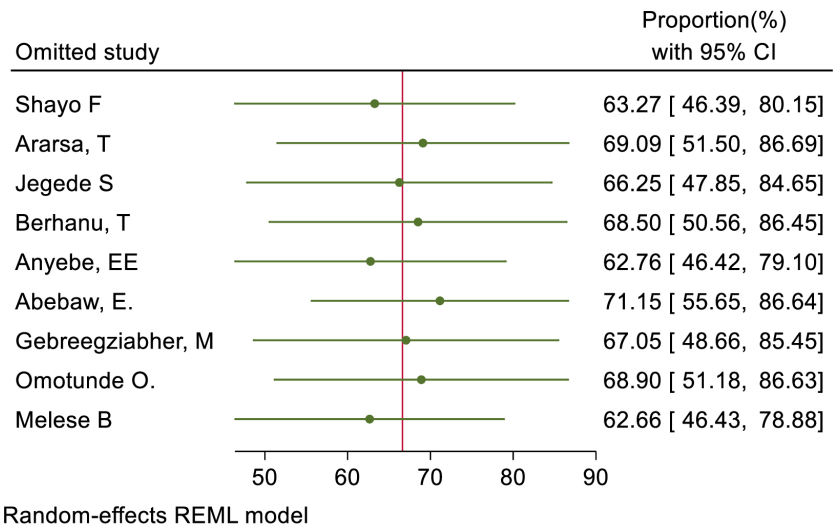

FIGURE 20
Sensitivity analysis for positive status of respondents towards cervical cancer screening among health care providers in Sub Saharan Africa, 2023.

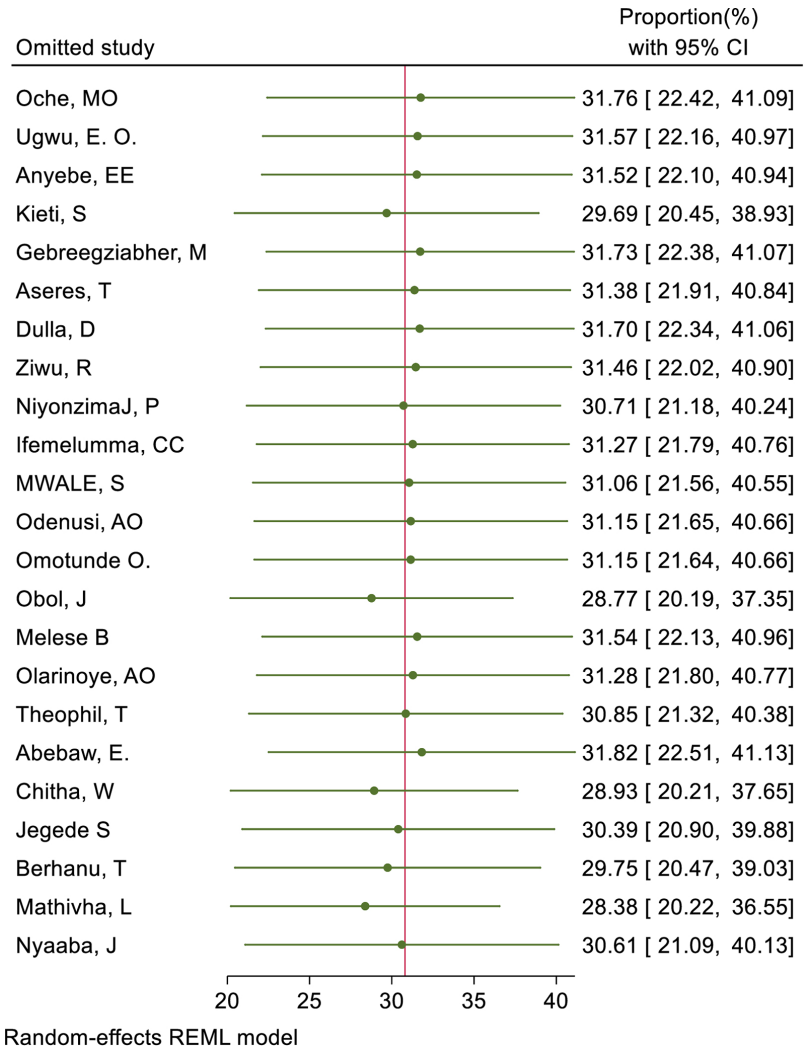

FIGURE 21
Sensitivity analysis for ever screened practice of female healthcare providers towards cervical cancer in Sub Sahara Africa, 2023.

This review also found that 72.02% of healthcare providers know about pap smears as a way to screen for cervical cancer. Around 46.15% are aware of the HPV DNA test as a screening method, while 41.68% know about VIA and 35.54% know about VILI. Additionally, 30.18% are aware of both pap smears and VIA, and 23.92% are aware of either VIA or VILI as screening methods for cervical cancer. Healthcare providers in Sub-Saharan Africa are more knowledgeable and experienced in using pap smears for cervical cancer screening compared to other methods like VIA, VILI, or HPV tests. This is because pap smears have been widely used in healthcare facilities in the region. About 27.34% of healthcare providers were aware of the regular interval for cervical cancer screening. this finding is low as comparable with 39% in Pakistan (74). This difference could be explained by the variations in the sociodemographic characteristics of the study participants and the disparities quality of training they received.

A systematic review in Sub-Saharan Africa found that the COVID-19 pandemic has led to disruptions in cervical cancer screening, diagnosis, and treatment services due to factors such as transportation limitations, staff shortages, and patients' fears of contracting the virus. To address these challenges, telemedicine and virtual platforms have been utilized for patient consultations and follow-ups during the pandemic in the region (84).

TABLE 3 Meta-regression of attitude and practice of cervical cancer screening among health care providers in Sub Saharan Africa, 2023.

Domain	Variables	Coefficient	LCL	UCL	P-value
Attitude status	Publication year	1.80	-4.83	8.44	0.59
	Sample size used	-0.23	-0.39	-0.06	<0.01
Practice	Publication year	3.84	1.14	6.55	<0.01
	Sample size used	-0.05	-0.13	0.02	0.15

Strengths and limitations of the study

The strengths of this review include being the first to examine the knowledge, attitude, and practice of health providers in sub-Saharan Africa regarding cervical cancer screening. Additionally, the review followed PRISMA guidelines and incorporated both published and unpublished research. However, a limitation of the review is that only studies written in English were included in the review.

Conclusions and recommendation

The level of knowledge, attitude, and practice of cervical cancer screening among healthcare providers in Sub-Saharan Africa was suboptimal. Healthcare providers need to take an active role in promoting women's health and preventing disease. This involves ensuring that healthcare professionals are knowledgeable about cervical cancer and its screenings, as well as having a positive outlook towards screening and being screened themselves. It is important to educate healthcare providers about misconceptions regarding cervical cancer screening and to increase awareness of the availability of these services in various centers across the country. Given the impact that their knowledge, attitude and practice can have on a large number of clients, it is imperative that swift action be taken. This could include providing training to participants to enhance their understanding, influence their beliefs, and encourage more individuals to utilize screening services. These efforts will help reduce the occurrence of cervical cancer among high-risk women. Hence, Policymakers as well as program implementers need to enhance the level of knowledge, attitude status, and screening habits of healthcare providers towards cervical cancer. Thus, healthcare providers should be role models for all other women for those services delivered to patients.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

AD: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. EB: Conceptualization, Data curation, Supervision, Visualization, Writing – original draft, Writing – review & editing. TA: Conceptualization, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. MT: Conceptualization, Data curation, Investigation, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. EF: Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. DE: Formal analysis, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. HE: Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. OA: Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. AT: Conceptualization, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. NK: Conceptualization, Data curation, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Genomics B. *Empowering women's health: BGI Genomics Global 2023 state of cervical cancer awareness report*. (2023).

2. Prabhu M, Eckert LO. Development of World Health Organization (WHO) recommendations for appropriate clinical trial endpoints for next-generation Human Papillomavirus (HPV) vaccines. *Papillomavirus Res*. (2016) 2:185–9. doi: 10.1016/j.pvr.2016.10.002

3. De Vuyst H, Alemany L, Lacey C, Chibwesha CJ, Sahasrabuddhe V, Banura C, et al. The burden of human papillomavirus infections and related diseases in sub-saharan Africa. *Vaccine*. (2013) 31:F32–46. doi: 10.1016/j.vaccine.2012.07.092

4. Bruni L, Albero G, Serrano B, Mena M, Gómez D, Muñoz J, et al. ICO/IARC information centre on HPV and cancer (HPV information centre). *Human papillomavirus and related diseases in the world Summary Report*. (2019) 17(6).

5. Cohen PA, Jhingran A, Oaknin A, Denny L. Cervical cancer. *Lancet*. (2019) 393:169–82. doi: 10.1016/S0140-6736(18)32470-X

6. Zhang S, Xu H, Zhang L, Qiao Y. Cervical cancer: Epidemiology, risk factors and screening. *Chin J Cancer Res*. (2020) 32:720. doi: 10.21147/j.issn.1000-9604.2020.06.05

7. Wang Z, Wang J, Fan J, Zhao W, Yang X, Wu L, et al. Risk factors for cervical intraepithelial neoplasia and cervical cancer in Chinese women: large study in Jiexiu, Shanxi Province, China. *J Cancer*. (2017) 8:924. doi: 10.7150/jca.17416

8. Rerucha CM, Caro RJ, Wheeler VL. Cervical cancer screening. *Am Family physician*. (2018) 97(7):441–8.

9. Organization WH, Health WHOR, Diseases WHOC and Promotion H. *Comprehensive cervical cancer control: a guide to essential practice*. World Health Organization (2006).

10. Rodríguez AC, Schiffman M, Herrero R, Wacholder S, Hildesheim A, Castle PE, et al. Rapid clearance of human papillomavirus and implications for clinical focus on persistent infections. *J Natl Cancer Institute*. (2008) 100:513–7. doi: 10.1093/jnci/djn044

11. Bosch FX, Manos MM, Muñoz N, Sherman M, Jansen AM, Peto J, et al. Prevalence of human papillomavirus in cervical cancer: a worldwide perspective. *Obstet Gynecol Surv*. (1995) 50:725–7. doi: 10.1097/00006254-199510000-00015

12. Louie KS, De Sanjose S, Mayaud P. Epidemiology and prevention of human papillomavirus and cervical cancer in sub-Saharan Africa: a comprehensive review. *Trop Med Int Health*. (2009) 14:1287–302. doi: 10.1111/j.1365-3156.2009.02372.x

13. Elfström KM, Herweijer E, Sundström K, Arnheim-Dahlström L. Current cervical cancer prevention strategies including cervical screening and prophylactic human papillomavirus vaccination: a review. *Curr Opin Oncol*. (2014) 26:120–9. doi: 10.1097/CCO.0000000000000034

14. Bristow RE, Chang J, Ziogas A, Campos B, Chavez LR, Anton-Culver H. Impact of National Cancer Institute Comprehensive Cancer Centers on ovarian cancer treatment and survival. *J Am Coll Surg*. (2015) 220:940–50. doi: 10.1016/j.jamcollsurg.2015.01.056

15. Koliopoulos G, Nyaga VN, Santesso N, Bryant A, Martin-Hirsch PP, Mustafa RA, et al. Cytology versus HPV testing for cervical cancer screening in the general population. *Cochrane Database Syst Rev*. (2017) 2017(8). doi: 10.1002/14651858.CD008587.pub2

16. Othman S, Darus F, Arshad R. The influence of coercive isomorphism on corporate social responsibility reporting and reputation. *Soc Responsibility J*. (2011) 7:119–35. doi: 10.1108/17471111111114585

17. Cuhls KE. Horizon Scanning in Foresight–Why Horizon Scanning is only a part of the game. *Futures Foresight Sci*. (2020) 2:e23. doi: 10.1002/ffo2.23

18. Devine D, Gaskell J, Jennings W, Stoker G. Trust and the coronavirus pandemic: What are the consequences of and for trust? An early review of the literature. *Political Stud Rev*. (2021) 19:274–85. doi: 10.1177/1478929920948684

19. Khan MJ, Werner CL, Darragh TM, Guido RS, Mathews C, Moscicki A-B, et al. ASCCP colposcopy standards: role of colposcopy, benefits, potential harms, and terminology for colposcopic practice. *J Low Genit Tract Dis*. (2017) 21:223–9. doi: 10.1097/LGT.0000000000000338

20. Cruz CT. Usos conceptuales del género y la vulnerabilidad en políticas públicas de atención al Virus del Papiloma Humano (VPH) y al Cáncer Cervicouterino (CaCu) en México. *Saúde em Debate*. (2022) 46:318–30. doi: 10.1590/0103-1104202213305

21. Organization WH. *Global strategy to accelerate the elimination of cervical cancer as a public health problem*. World Health Organization (2020).

22. Organization WH. *WHO guidelines for screening and treatment of precancerous lesions for cervical cancer prevention: supplemental material: GRADE evidence-to-recommendation tables and evidence profiles for each recommendation*. World Health Organization (2013).

23. Ifemelumma C, Anikwe C, Okorochukwu B, Onu F, Obuna J, Ejikeme B, et al. Cervical cancer screening: assessment of perception and utilization of services among health workers in low resource setting. *Int J Reprod Med*. (2019) 2019:6505482. doi: 10.1155/2019/6505482

24. American Cancer Society. *Cancer facts & Figures 2019*. Atlanta, Ga: American Cancer Society (2019).

25. American Cancer Society. *Cancer prevention & Early detection facts & Figures 2019-2020*. Atlanta, Ga: American Cancer Society (2019).

26. Leung SS, Leung I. Cervical cancer screening: knowledge, health perception and attendance rate among Hong Kong Chinese women. *Int J women's Health*. (2010) 2010:221–8. doi: 10.2147/IJWH

27. Pierz AJ, Randall TC, Castle PE, Adedimeji A, Ingabire C, Kubwimana G, et al. A scoping review: Facilitators and barriers of cervical cancer screening and early diagnosis of breast cancer in Sub-Saharan African health settings. *Gynecol Oncol Rep*. (2020) 33:100605. doi: 10.1016/j.gore.2020.100605

28. Randall TC, Ghebre R. Challenges in prevention and care delivery for women with cervical cancer in sub-Saharan Africa. *Front Oncol*. (2016) 6:160. doi: 10.3389/fonc.2016.00160

29. Adedimeji A, Ajeh R, Pierz A, Nkeng R, Ndenkeh JJ, Fuhngwa N, et al. Challenges and opportunities associated with cervical cancer screening programs in a low income, high HIV prevalence context. *BMC women's Health*. (2021) 21:1–14. doi: 10.1186/s12905-021-01211-w

30. Soylar P, Özer A, Doğan Yüksekol Ö, Ulucan M. Knowledge, attitude, and practice regarding cancer screening tests among health workers in a university hospital in Turkey. *J Cancer Education*. (2020) 35:718–23. doi: 10.1007/s13187-019-01517-2

31. Sumampouw OJ, Nelwan JE, Rumayar AA. *Outline Images Download Cite Share Favorites Permissions ORIGINAL ARTICLE Socioeconomic Factors Associated with Diarrhea among Under-Five Children in Manado Coastal Area, Indonesia*. (2019).

32. Hweissa NA, Lim JN, Su T. Health-care providers' perceptions, attitudes towards and recommendation practice of cervical cancer screening. *Eur J Cancer Care*. (2016) 25:864–70. doi: 10.1111/ecc.2016.25.issue-5

33. Gebreegziabher M, Asefa NG, Berhe S. Factors Affecting the Practices of Cervical Cancer Screening among Female Nurses at Public Health Institutions in Mekelle Town, Northern Ethiopia, 2014: A Cross-Sectional Study. *J Cancer Res*. (2016) 2016:4743075. doi: 10.1155/2016/4743075

34. Anyebe E, Opaluwa S, Muktar H, Philip F. Knowledge and practice of cervical cancer screening amongst nurses in Ahmadu Bello University Teaching Hospital Zaria. *Cancer*. (2014) 4(27):33–40.

35. Abebaw E, Tesfa M, Gezimu W, Bekele F, Duguma A. Female healthcare providers' knowledge, attitude, and practice towards cervical cancer screening and associated factors in public hospitals of Northwest Ethiopia. *SAGE Open Med*. (2022) 10:20503121221095931. doi: 10.1177/20503121221095931

36. Chitha W, Sibulawa S, Funani I, Swartbooi B, Maake K, Hellebo A, et al. A cross-sectional study of knowledge, attitudes, barriers and practices of cervical cancer screening among nurses in selected hospitals in the Eastern Cape Province, South Africa. *BMC Women's Health*. (2023) 23:94. doi: 10.1186/s12905-023-02251-0

37. Arulogun OS, Maxwell OO. Perception and utilization of cervical cancer screening services among female nurses in University College Hospital, Ibadan, Nigeria. *Pan Afr Med J*. (2012) 11(1).

38. Alamneh Y, Adane F, Yirga T, Desta M. Essential newborn care utilization and associated factors in Ethiopia: a systematic review and meta-analysis. *BMC pregnancy childbirth*. (2020) 20:1–9. doi: 10.1186/s12884-020-2804-7

39. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *Eur J Epidemiol*. (2010) 25:603–5. doi: 10.1007/s10654-010-9491-z

40. Rendina-Gobioff G. *Detecting publication bias in random effects meta-analysis: An empirical comparison of statistical methods*. (2006).

41. Kossmeier M, Tran US, Voracek M. Visual inference for the funnel plot in meta-analysis. *Zeitschrift für Psychologie*. (2019). doi: 10.1027/2151-2604/a000358

42. Egger M, Smith GD, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *bmj*. (1997) 315:629–34. doi: 10.1136/bmj.315.7109.629

43. Begg CB, Mazumdar M. Operating characteristics of a rank correlation test for publication bias. *Biometrics*. (1994) 1994:1088–101. doi: 10.2307/2533446

44. Ndizeye Z, Vanden Broeck D, Vermandere H, Bogers JP, Van Geertruyden JP. Knowledge and practices of general practitioners at district hospitals towards cervical cancer prevention in Burundi, 2015: a cross-sectional study. *Global Health*. (2018) 14:4. doi: 10.1186/s12992-018-0321-5

45. NiyonzimaJ P, MatabelleL B, Ntasumbumuyange D, Rulisa S. Cervical cancer prevention knowledge and attitudes: Survey of midwives and nurses in Rwanda. *Int J Cancer Tremnt*. (2018) 1(1):30–4.

46. Kieti SN. *Knowledge, attitude and practices on cervical cancer screening and prevention methods among nurses at two Nairobi hospitals in Kenya. submitted in accordance with the requirements for the degree of master of arts in nursing science at the university of south Africa*. (2016).

47. Gebreegziabher M, Asefa NG, Berhe S. Factors Affecting the Practices of Cervical Cancer Screening among Female Nurses at Public Health Institutions in Mekelle Town, Northern Ethiopia, 2014: A Cross-Sectional Study. *J Cancer Res*. (2016) 2016 (1):4743075.

48. Berhanu T, Mamo E, Tewolde T, Beshir M. Knowledge of cervical Cancer and its screening practice among health extension Workers in Addis Ababa, Ethiopia. *Prim Health Care*. (2019) 9(1):1–5.

49. Melese Bekele A. *Utilization of cervical cancer screening service and associated factors among female health workforces in public health institutions in bale zone*. South East Ethiopia: HU (2021).

50. Ararsa T, Tadele N, Ayalew Y, Gela D. Knowledge towards cervical cancer screening and associated factors among urban health extension workers at Addis Ababa, Ethiopia: facility based cross-sectional survey. *BMC cancer*. (2021) 21:1–9. doi: 10.1186/s12885-021-07952-z

51. Getahun F, Addissie A, Negash S, Gebremichael G. Assessment of cervical cancer services and cervical cancer related knowledge of health service providers in public health facilities in Addis Ababa, Ethiopia. *BMC Res Notes*. (2019) 12:675. doi: 10.1186/s13104-019-4701-6

52. Addissie A. *College Of Healthscience School Of Public Health Assessment Of Knowledge And Attitude Of Cervical Cancer And Screening Among Primary Health Care Workers Of West Wollega Zone, Ethiopia, 2016*. ADDIS ABABA UNIVERSITY (2016).

53. Theophil T, Balandya B, Kunambi P, Wangwe PJ, August F. Knowledge, utilization, challenges and factors associated with cervical cancer screening among female doctors and nurses at a tertiary hospital in Tanzania: A cross sectional study. (2022). doi: 10.21203/rs.3.rs-2136119/v1

54. Obol JH, Lin S, Obwolo MJ, Harrison R, Richmond R. Knowledge, attitudes, and practice of cervical cancer prevention among health workers in rural health centres of Northern Uganda. *BMC cancer*. (2021) 21:1–15. doi: 10.1186/s12885-021-07847-z

55. Dulla D, Daka D, Wakgari N. Knowledge about cervical cancer screening and its practice among female health care workers in southern Ethiopia: a cross-sectional study. *Int J Women's Health*. (2017) 9:365–72. doi: 10.2147/IJWH

56. Aseres T. *Knowledge, practice and associated factors of cervical cancer screening among women health workers in Gondar University teaching and referral hospital*. Gondar, Ethiopia: University of Gondar (2016).

57. Oche M, Kaoje A, Gana G, Ango J. Cancer of the cervix and cervical screening: Current knowledge, attitude and practices of female health workers in Sokoto, Nigeria. *Int J Med Med Sci*. (2013) 5(4):184–90.

58. Ziwu R. *Cervical cancer knowledge and screening behaviors amongst female health professionals in some selected health facilities in the La Nkwantanang Madina Municipality in the Greater Accra Region of Ghana*. Ensign Global College (2017).

59. Odenusi A, Oladoyin V, Asuzu M. Uptake of cervical cancer screening services and its determinants between health and non-health workers in Ibadan, south-Western Nigeria. *Afr J Med Med Sci*. (2020) 49(4):573–84.

60. Olarinoye A, Shiru M, Ubom A, Olabinjo A, Abdul I, Ijarotimi O, et al. Knowledge, attitude and uptake of pap smear among female healthcare professionals in a Nigerian teaching hospital. *Ann Health Res*. (2021) 7:391–402. doi: 10.30442/ahr.0704-07-149

61. Ogunsuyi GO, Ademuyiwa IY, Anorkuru R. Awareness and utilization of cervical cancer screening among primary health care workers in ilesa, osun state. *Int J Nursing Midwife Health Related Cases*. (2022) 8:39–52. doi: 10.37745/ijnmh.15

62. Nyaaba JA, Akurugu E. Knowledge, barriers and uptake towards Cervical Cancer screening among female health workers in Ghana: A perspective of the Health Belief Model. *Int J Afr Nurs Sci*. (2023) 19:100587. doi: 10.1016/j.ijans.2023.100587

63. Logbo-Akey KE, Ajavon DR, M'bortche KB, Kambote PY, Patidi KN, Aboubakari AS. Cervical cancer screening by midwives in the kara region of northern Togo: knowledge, attitudes and practices. *Open J Obstet Gynecol*. (2022) 12:140–6. doi: 10.4236/ojog.2022.122014

64. Jegede Solomon O, Christianah O, Ogun FO. *Attitude and uptake of cervical cancer screening among female health care workers in ogbomoso, oyo state*.

65. Ugwu E, Obi S, Ezechukwu P, Okafor I, Ugwu A. Acceptability of human papilloma virus vaccine and cervical cancer screening among female health-care workers in Enugu, Southeast Nigeria. *Niger J Clin Pract*. (2013) 16(2):249–52.

66. Omotunde OI, Amosu Ademola M. Knowledge, perception and cervical cancer screening practices among female nurses working in healthcare facilities in Lagos State, Nigeria. *Pharmacology*. (2020) 1(1):74–92.

67. Shayo FS. *Knowledge, Attitudes and Practices (KAP) on cervical cancer screening health care workers in Oshikoto region*. Namibia: University of Namibia (2018).

68. Mathivha L, Ramathuba DU, Maputle MS. Factors affecting participation in cervical screening by female nurses in public health institutions in vhembe district, limpopo province. *Nurs Rep*. (2023) 13:424–35. doi: 10.3390/nursrep13010039

69. Chitha W, Sibulawa S, Funani I, Swartbooi B, Maake K, Hellebo A, et al. A cross-sectional study of knowledge, attitudes, barriers and practices of cervical cancer screening among nurses in selected hospitals in the Eastern Cape Province, South Africa. *BMC Women's Health*. (2023) 23:1–12. doi: 10.1186/s12905-023-02251-0

70. Mwale S. *Assessment of knowledge on cervical cancer and utilization of cervical cancer screening services among female nurses at Solwezi General Hospital in Zambia*. (2020).

71. Ndizeye Z, Vanden Broeck D, Vermandere H, Bogers JP, Van Geertruyden J-P. Knowledge and practices of general practitioners at district hospitals towards cervical cancer prevention in Burundi, 2015: a cross-sectional study. *Globalization Health*. (2018) 14:1–8. doi: 10.1186/s12992-018-0321-5

72. Aldarmahi A, Alzahrani H, Alqutub S, Alzahrani F. Exploring the attitudes and practices of female doctors towards cervical cancer screening in primary health care centers. *J Med Life*. (2023) 16:773. doi: 10.25122/jml-2022-0344

73. Chawla B, Taneja N, Awasthi AA, Kaur KN, Janardhanan R. Knowledge, attitude, and practice on screening toward cervical cancer among health professionals in India—A review. *Women's Health*. (2021) 17:17455065211017066. doi: 10.1177/17455065211017066

74. Syed S. A Survey of Cervical Cancer and Pap Smear Awareness and Utilization of Pap smear test among female health care providers in a Secondary Care Hospital, Pakistan. *J Soc Obstetricians Gynaecologists Pakistan*. (2018) 8(3):143–7.

75. Mohamed ML, Tawfik AM, Mohammed GF, Elotla SF. Knowledge, attitude, and practice of cervical cancer screening, and HPV vaccination: A cross-sectional study among obstetricians and gynecologists in Egypt. *Maternal Child Health J*. (2022) 26:565–74. doi: 10.1007/s10995-021-03352-8

76. Di J-L, Song B, Rutherford S, Wu J-L, Ma L, Chen J-Y, et al. Knowledge of cervical cancer screening among health care workers providing services across different socio-economic regions of China. *Asian Pacific J Cancer Prev*. (2016) 17(6):2965–72.

77. Heena H, Durrani S, AlFayyad I, Riaz M, Tabasim R, Parvez G, et al. Knowledge, Attitudes, and Practices towards Cervical Cancer and Screening amongst Female Healthcare Professionals: A Cross-Sectional Study. *J Oncol*. (2019) 2019:5423130. doi: 10.1155/2019/5423130

78. Nilaweera R, Perera S, Paranagama N, Anushyanthan A. Knowledge and practices on breast and cervical cancer screening methods among female health care workers: a Sri Lankan experience. *Asian Pacific J Cancer Prev*. (2012) 13:1193–6. doi: 10.7314/APJCP.2012.13.4.1193

79. Yimer NB, Mohammed MA, Solomon K, Tadese M, Grutzmacher S, Meikena HK, et al. Cervical cancer screening uptake in Sub-Saharan Africa: a systematic review and meta-analysis. *Public Health*. (2021) 195:105–11. doi: 10.1016/j.puhe.2021.04.014

80. Alali A, Salem M, Elmahdi H, Alkubaisi N, Alwahedi Z, Taher M, et al. Knowledge, attitudes and practices regarding cervical cancer screening among female health care workers in primary healthcare in Qatar. *World Family Med Journal: Incorporating Middle East J Family Med*. (2016) 99:1–12. doi: 10.5742/MEWFM.2016.92809

81. Coskun S, Can H, Turan S. Knowledge about cervical cancer risk factors and pap smear testing behavior among female primary health care workers: a study from south Turkey. *Asian Pacific J Cancer Prev*. (2013) 14:6389–92. doi: 10.7314/APJCP.2013.14.11.6389

82. Khatuja R, Mittal S, Asthana U, Verma M, Kadian M. Knowledge and practice of cervical cancer screening in general population and medical personnel: A gap to be bridged. *Asian J Med Sci*. (2022) 13(2):61–4. doi: 10.3126/ajms.v13i2.40582

83. Tran NT, Taylor R, Choe SI, Pyo HS, Kim OS, So HC. Knowledge, attitude and practice (KAP) concerning cervical cancer and screening among rural and urban female healthcare practitioners in the Democratic People's Republic of Korea. *Asian Pac J Cancer Prev*. (2011) 12(11):3023–8.

84. Rine S, Lara ST, Bikomeye JC, Beltrán-Ponce S, Kibudde S, Niyonzima N, et al. The impact of the COVID-19 pandemic on cancer care including innovations implemented in Sub-Saharan Africa: A systematic review. *J Global Health*. (2023) 13. doi: 10.7189/jogh.13.06048

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The landscape of perioperative nursing education in Africa: a scoping review

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Background: Not everyone across the globe has access to safe surgical care. There exist stark disparities in surgical mortality between high-income and low- and middle-income countries. Quality perioperative care across the surgical care continuum can mitigate these disparities. Nurses play a vital role in providing quality perioperative care and their competency in perioperative nursing directly impacts surgical outcomes. Across Africa, formal educational opportunities for nurses in perioperative care is not well understood.

Methods: This is an informal scoping review of the existing literature investigating the current state of perioperative nursing education across the African continent. Ten articles were included in the analysis.

Results: Few programs exist across Africa that provide specialized training for nurses in perioperative medicine. Programs that have been formally evaluated show improved knowledge and clinical skills among nurses.

Conclusion: Greater research is necessary to establish a more robust evidence base in support of increasing access to perioperative nursing education to improve patient outcomes. Obstacles remain to designing, implementing, and evaluating new educational programs.

KEYWORDS

perioperative, surgery, nursing, nursing education, Africa

1 Introduction

Access to safe surgical care is a pressing global and public health problem. It is estimated that 4.8 billion people globally do not have access to surgical care and that at least 4.2 million people die each year within the first 30 days after surgery (1, 2). Disparities in access to surgical care exist, with greater than 95% of the unmet needs for surgical care found in low- and middle-income countries (LMICs) (2). Similar disparities exist in the distribution of these deaths, with LMICs experiencing a disproportionate burden of postoperative deaths compared to high-income countries (HICs). One group estimated that half of the deaths that occur within the first 30 days after surgery take place in LMICs (1).

Additionally, a study conducted by the GlobalSurg Collaborative (3) found that the 30-day mortality for abdominal surgery was three times higher in LMICs compared to HICs, even after being adjusted for prognostic factors (2016).

Optimizing perioperative care provides a potential solution to improve patient outcomes and reduce postoperative deaths by delivering patient-centered, multidisciplinary care across the surgical continuum of care (4, 5). Perioperative care requires an interdisciplinary team of healthcare providers, including an adequate number of trained nurses, to optimize patient outcomes. Perioperative nurses impact surgical outcomes at all intersections along the surgical care continuum and, therefore, play a critical role in perioperative medicine both in and outside of the operating room.

In May 2023, the World Health Organization (WHO) called for countries to integrate operative care into nursing curricula and offer postgraduate operative care training for nurses under Resolution WHA76.2 (6). Increasing access to perioperative education for nurses is associated with greater clinical knowledge and improved practice in perioperative settings. In one example, a cross-sectional study in Ethiopia assessing nurses' practices with perioperative hypothermia prevention found that nurses with a bachelor's degree, master's degree, or other specialized perioperative training had better knowledge of the prevention of perioperative hypothermia compared to nurses with more limited educational training (7).

Although nurses comprise 37% of the 3.6 million health workers in Africa, nursing education varies greatly across the continent and many nurses do not have access to perioperative education as a nursing subspecialty (8). There is a gap in the literature evaluating the current availability of perioperative nursing education in Africa. The purpose of this article is to provide a landscape of the available perioperative nursing education opportunities across the African continent, hypothesizing that greater access to perioperative education for nurses is associated with safe surgical care, including reduced surgery-related deaths and improved patient outcomes.

2 Methods

This review aims to answer the following research question: What is the current landscape of perioperative education among nurses in Africa? This was achieved through a scoping review of the relevant literature using the PRISMA-ScR Checklist (9). Articles were considered for inclusion if they were related to nursing education or training in Africa across the perioperative continuum of care and if they were available in English. Articles were excluded if there was no abstract or author information available, or if the full text of the article was not available online.

The initial aim was to evaluate nursing education programs in Africa that have a perioperative subspecialty, however, the preliminary search in the electronic databases PubMed and CINAHL revealed few studies. As a result, the search terms were expanded to include surgical training and surgical nursing clinical competencies. After a search was generated, each article title and abstract was then reviewed for the inclusion and exclusion criteria. The search descriptors used in PubMed were as follows:

- *(((perioperative nurse education in Africa) AND "Africa"[MeSH]) AND "Perioperative Nursing"[MAJR]) AND "Perioperative Nursing/education"[MeSH]*
- *((((perioperative nurse education) AND (training)) AND (surgery)) AND (nurse) AND (Africa))*
- *(((critical care nursing in low middle income setting) AND (training) AND (nursing))*

A total of 77 articles were generated using these search terms, however, only 14 (18.2%) were selected for further review based on the relatedness of the title and abstract to the inclusion and exclusion criteria. The search descriptors used to generate relevant articles in CINAHL were: *(Perioperative nursing education) AND "Africa."* A total of 7 articles resulted from the search and based on a review of the article titles and abstracts, 1 (14.3%) was selected for additional use of the study criteria. To supplement the small number of selected articles, a general search on Google Scholar was conducted using "*perioperative nursing education in Africa AND training AND curriculum AND competencies AND nursing*" as search criteria. The titles and abstracts of the generated articles were reviewed, resulting in the selection of an additional 7 articles for further review.

Of note, while nurse anesthetists are nurses in the perioperative space that contribute significantly to providing quality surgical care, this review did not include anesthesia training and focused solely on perioperative nurse training.

The selected studies were then charted and analyzed for key findings across several phases. The titles and abstract were read and entered into an Excel sheet, as well as the author names, publication date, country of origin, and country of settlement – the country the article was evaluating (10). A total of 22 articles were read in full by one author and analyzed for their relatedness to the research question. Of the 22 articles that were reviewed in full, 10 were selected for the scoping review as reflected in Table 1, and 12 were excluded from further evaluation. Relevant gray literature was also included in the results to provide greater context to the study findings, such as the Global Profile of Nursing Regulation, Education, and Practice published by the National Council of State Boards of Nursing (11). The results and findings from each article were summarized in the Excel chart and then evaluated for patterns and trends.

3 Results

General nursing education is well-established across Africa. The National Council of State Boards of Nursing compiled data from 43 African countries, revealing that the mean length of general nursing education programs on the continent is 3.25 years, although the majority of programs are 3–4 years (11). Burundi and Gambia had the shortest nursing program lengths of those examined, with a duration of 2 and 2.5 years, respectively (11). After completing their training, all nurses must pass an examination before they are able to practice any nursing role, except for

TABLE 1 Articles included in analysis.

Article title	References	Country of settlement	Country of origin
Building the Case for Nurses' Continuous Professional Development in Ethiopia: A Qualitative Study of the Sick Kids-Ethiopia Pediatrics Perioperative Nursing Training Program	Abebe et al. (19)	Ethiopia	Ethiopia and Canada
National surgical, obstetric, anesthesia and nursing plan, Nigeria	Seyi-Olajide et al. (15)	Nigeria	Nigeria and United States
Critical care nursing practice and education in Rwanda	Munyiginya et al. (13)	Rwanda	Rwanda, South Africa, and Canada
Perioperative Nursing Training in Rwanda in Partnership with American Universities: The Journey So Far | Rwanda Journal of Medicine and Health Sciences	Mukantwari et al. (14)	Rwanda	Rwanda
Anesthetic nurse training in KwaZulu-Natal government hospitals: exploring strengths and deficiencies | Southern African Journal of Anesthesia and Analgesia	Maharaj et al. (20)	South Africa	South Africa
The development of critical care nursing education in Zambia	Carter et al. (21)	Zambia	Zambia, United Kingdom
Improving Perioperative Nursing Practices in Africa	Woodhead (17)	African Continent	United Kingdom
Perioperative Nursing E-Learning Foundational Programme (PeN Programme)	The UN Global Surgery Learning Hub (18)	Online	ECSA Health Community, Ireland
A Global Profile of Nursing Regulation, Education, and Practice	National Council of State Boards of Nursing (11)	Global	n/a
Higher Diploma in Peri-Operative Theater Nursing	Nairobi Women's Hospital College (12)	Kenya	Kenya

Botswana, Gambia, and Mauritius, which only require an exam for some nursing roles (11).

3.1 Perioperative nursing education opportunities

In Kenya, the Nairobi Women's Hospital College hosts a higher diploma in perioperative theater nursing that is 1 year long (12). To be eligible, applicants must have a diploma in nursing or other nursing degree and at least 1 year of prior working experience (12). The program was designed to provide nurses with the skills and competence to provide specialized care to patients across the surgical continuum of care. The college also offers a higher diploma in critical care nursing (12).

In 2012, the Rwandan Ministry of Health (MoH) developed a 7-year project called the Human Resources for Health (HRH) in collaboration with the United States (US) government to increase the number of healthcare professionals in Rwanda, including nurses. Prior to this project, nurses typically were trained in critical care nursing on the job or traveled abroad to obtain further specialized training (13). The Rwandan MoH aimed to develop new nursing education programs, including critical care programs, under the mentorship of US faculty (13). One such program exists at the University of Rwanda (UR). The university created a Master's in Perioperative Nursing program with the HRH under the MoH (14). The program consists of common and specialty modules taught in the classroom and clinical settings, as well as a dissertation (14). To improve the sustainability of the program, UR recruits its program graduates to join the training staff (14). Mukantwari et al. (14) reported on two graduated classes and found that 11 of the 19 sampled graduates work in teaching hospitals, while 7 of the 19 work in higher education (2021).

Nigeria included a plan to increase perioperative nurse retention in their National Surgical, Obstetric, Anesthesia, and Nursing Plan for 2019–2023. Smile Train, a nongovernmental organization that provides free cleft palate care in LMICs, implemented a perioperative nursing care program in 2021 called Nursing Care Saves Lives (15). An initial 24 nurses are being trained as part of a pilot program that utilizes the train-the-trainer method in hopes of scaling up the program across the country (15). The training is 5 days long and provides nurses with the skills they need to provide safe perioperative care to children with clefts (16). The efficacy of the pilot program is yet to be evaluated.

Additionally, international organizations have implemented specialized perioperative training programs in Africa. Friends of African Nursing (FoAN) is a charity based in the United Kingdom (UK) that aims to provide perioperative education for nurses in partnership with the WHO Safe Surgery Saves Lives campaign (17). FoAN volunteers teach week-long programs delivered over the course of 4 years consisting of theory-based curricula, clinical practice programs, and leadership courses (17). The organization utilizes to train-the-trainer method in which nurses are trained to teach the curriculum and are then provided with seed funding from FoAN to develop new perioperative educational programs in Africa (17).

Virtual learning opportunities are also available to nurses who wish to strengthen their perioperative skillset. For instance, East, Central, and Southern Africa College of Nursing and Midwifery (ECSACONM) created the Perioperative Nursing E-Learning Foundational Programme (PeN Programme) and it is now offered online on the learning platform the UN Global Surgery Hub (18). The program is provided open-access and free of charge and

consists of 30 1-h long modules that are asynchronous and self-paced (18). The purpose of the course is to strengthen nurses' theoretical and practical understanding of how to deliver high-quality care in surgical care settings (18).

3.2 Evaluation of perioperative nursing education programs

A qualitative evaluation of the Sick Kids-Ethiopia Pediatrics Perioperative Nursing Training program evaluated the training experience of nine nurses who completed the program (19). The program is 4 weeks longs and consists of classroom sessions and practical assessments (19). The study findings indicated that participants had improved knowledge, skills, confidence, and job retention following the completion of the program (19). A similar study was conducted investigating the state of anesthetic nurse training in the KwaZulu-Natal government hospitals in South Africa (20). The study consisted of 73 qualitative interviews (20). However, the authors reported that 76% of program participants had no anesthetic training in nursing school, leading to insufficient knowledge of their current practice (20). The authors also concluded that subsequent workplace training was not sufficient (20).

In Zambia, nursing is regulated by the Nurses and Midwifery Act of 2001, and all nursing education must be competence-based to ensure nurses are able to provide high-quality and comprehensive care to patients (21). The Lusaka College of Nursing implemented a year-long Advanced Diploma in Critical Care Nursing in 2012 in collaboration with the General Nursing Council of Zambia (21). The program instruction consists of 19 weeks of theoretical curriculum and 32 weeks of practical training (21). An evaluation of the program indicated that it was effective in increasing nurses' knowledge and skills in critical care delivery (21). As a result, the MoH in Zambia aims to use this program as the foundation to develop a Bachelor of Science in critical care nursing (21).

4 Discussion

Despite the advancement of perioperative care as a nursing subspecialty, significant barriers remain in countries developing their perioperative nursing workforce. Quality perioperative care requires not only quality education, but also an adequate number of nurses in the workforce. Many African countries are experiencing severe nursing shortages. According to the WHO, approximately 81% of the world's nursing workforce is located in the Americas, Europe, and Western Pacific, despite only comprising 51% of the world's total population (2020). This imbalance is largely due to income-driven, with HICs having a nursing density of 107.7 nurses per 10,000 population while the nursing density in LMICs is 9.1 nurses per 10,000 population (22). Thus, despite the well-defined and central role of nurses in surgical care, many LMICs lack the available nursing personnel to optimize care delivery.

Additionally, both current and aspiring nurses face several barriers to accessing perioperative education programs and supplemental training. Online programs, such as the PeN Programme offered by ECSACONM and the UN Global Surgery Hub, require access to a computer and a reliable wireless network. It is also difficult for practicing nurses to study while working, and nurses may be hesitant or unable to take time away from work to further their education as it can lead to a loss of income. Moreover, the cost of educational programs and training also acts as a deterrent.

The authors reflected on their experiences working in perioperative care throughout the surgical care continuum in the operating theater and acute and critical care settings. They discussed several additional possible explanations for why nurses may be hesitant to pursue additional perioperative education, including the lack of dedicated time to this patient population. In many regions of Africa, nurses rotate between wards, and thus, their exposure to this population is constrained by the amount of time they spend at each ward. This limits their ability to receive comprehensive perioperative training, as well as their ability to understand quality perioperative care and invest themselves into this population. Nurses may also lose their perioperative skills and knowledge after rotating to a new ward. Additionally, the authors also cited the presence of negative attitudes by some nurses toward working with patients in their perioperative areas. This could be due to a knowledge deficit and the challenges of learning new skills. Lastly, nurses may be hesitant to get further training because they do not see or experience the issues that would be better addressed with additional perioperative training.

This article, while comprehensive, may be limited in its application. This article is a compilation of the most recent and relevant existing literature but is not a reflection of all published studies. Additionally, the findings are limited by what information is available in the literature, which may not reflect all available educational opportunities for perioperative nurses. While the purpose of this article was to detail all professional nursing training programs dedicated to perioperative nursing in Africa, it must be acknowledged that general professional nursing training often includes competencies in surgical nursing. Additional research could include a review of the perioperative training and competencies within existing professional nursing programs. Lastly, the scope of this article did not include the contributions made by nurse anesthetists in perioperative care. Further research will create a stronger evidence base for investing in comprehensive perioperative nursing education to increase patient safety and improve health outcomes among surgical patients.

5 Conclusion

Providing greater perioperative educational opportunities for both prospective and existing nurses in LMICs has the potential to reduce disparities in surgical patient outcomes and improve inequities in the distribution of perioperative nurses across the globe. Beyond curriculum and educational program development, perioperative nursing programs must address barriers to accessing education to ensure student success by providing social, economic, and academic support, such as mentorship and opportunities for continued learning (23). Lack of funding, inadequate staffing, inadequate compensation, and lack of mentorship are among the ongoing obstacles countries face toward establishing new

perioperative nursing programs (24). It is critical to prioritize and advocate for the development of perioperative nursing through advancing education and research, as well as inclusion in local, regional, and national agendas, to provide safe surgical care to patients across the globe.

Author contributions

MW: Writing – review and editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. ZB: Writing – review and editing, Investigation, Conceptualization. JN: Writing – review and editing, Investigation, Conceptualization. NM: Writing – review and editing, Investigation, Conceptualization. EN: Writing – review and editing, Investigation, Conceptualization. RS: Writing – review and editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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References

1. Nepogodiev D, Martin J, Biccard B, Makupe A, Bhangu A, Nepogodiev D, et al. Global burden of postoperative death. *Lancet.* (2019) 393:401. doi: 10.1016/S0140-673633139-8

2. Alkire B, Raykar N, Shrime M, Weiser T, Bickler S, Rose J, et al. Global access to surgical care: A modelling study. *Lancet Glob Health.* (2015) 3:e316–23. doi: 10.1016/S2214-109X70115-4

3. GlobalSurg Collaborative. Mortality of emergency abdominal surgery in high-, middle- and low-income countries. *Br J Surg.* (2016) 103:971–88. doi: 10.1002/bjs.10151

4. Emond Y, Calsbeek H, Peters Y, Bloo G, Teerenstra S, Westert G, et al. Increased adherence to perioperative safety guidelines associated with improved patient safety outcomes: A stepped-wedge, cluster-randomised multicentre trial. *Br J Anaesth.* (2022) 128:562–73. doi: 10.1016/j.bja.2021.12.019

5. Wall J, Dhesi J, Snowden C, Swart M. Perioperative medicine. *Future Healthc J.* (2022) 9:138–43. doi: 10.7861/fhj.2022-0051

6. Reynolds T, Guisset A, Dalil S, Relan P, Barkley S, Kelley E. Emergency, critical and operative care services for effective primary care. *Bull World Health Organ.* (2020) 98:728A–728A. doi: 10.2471/BLT.20.280016

7. Woretaw A, Yimer Mekonnen B, Tsegaye N, Dellie E. Knowledge and practice of nurses with respect to perioperative hypothermia prevention in the Northwest AMHARA regional state referral hospitals, Ethiopia: A cross-sectional study. *BMJ Open.* (2023) 13:e068131. doi: 10.1136/bmjopen-2022-068131

8. Ahmat A, Okoroafor S, Kazanga I, Asamani J, Millogo J, Illou M, et al. The health workforce status in the WHO African region: Findings of a cross-sectional study. *BMJ Glob Health.* (2022) 7:e008317. doi: 10.1136/bmjgh-2021-008317

9. Page M, McKenzie J, Bossuyt P, Boutron I, Hoffmann T, Mulrow C, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ.* (2021) 372:n71. doi: 10.1136/bmj.n71

10. Microsoft Corporation. *Microsoft excel*. Redmond, WA: Microsoft Corporation (2024).

11. National Council of State Boards of Nursing. A global profile of nursing regulation, education, and practice. *J Nurs Regul.* (2020) 10:1–116. doi: 10.1016/S2155-825630039-9

12. Nairobi Women's Hospital College. *Higher diploma in peri-operative theatre nursing*. Nairobi: The Nairobi Women's Hospital College (2024).

13. Munyiginya P, Brysiewicz P, Mill J. Critical care nursing practice and education in Rwanda. *Southern Afr J Crit Care.* (2016) 32:55.

14. Mukantwari J, Omondi L, Ryamukuru D. Perioperative nursing training in Rwanda in partnership with American universities: The journey so far. *Rwanda J Med Health Sci.* (2021) 4:185–96. doi: 10.4314/rjmhs.v4i1.13

15. Seyi-Olajide J, Anderson J, Williams O, Faboya O, Amedu J, Anyanwu S, et al. National surgical, obstetric, anaesthesia and nursing plan, Nigeria. *Bull World Health Organ.* (2021) 99:883–91. doi: 10.2471/BLT.20.280297

16. Smile Train Africa. *Comprehensive education & training programs for cleft care*. Nairobi: Smile Train Africa (2024).

17. Woodhead K. Improving perioperative nursing practices in Africa. *AORN J.* (2010) 92:685–9. doi: 10.1016/j.aorn.2010.08.014

18. The UN Global Surgery Learning Hub. *Perioperative nursing e-learning foundational programme (PeN Programme)*. (2024). Available online at: https://www.surghub.org/course/pen-programme (accessed April 14, 2024).

19. Abebe L, Bender A, Pittini R. Building the case for nurses' continuous professional development in Ethiopia: A qualitative study of the sick kids-Ethiopia paediatrics perioperative nursing training program. *Ethiop J Health Sci.* (2018) 28:607–14. doi: 10.4314/ejhs.v28i5.12

20. Maharaj A, Cronjé L, Jithoo S. Anaesthetic nurse training in KwaZulu-Natal government hospitals: Exploring strengths and deficiencies. *Southern Afr J Anaesth Analg.* (2021) 27:15–23.

21. Carter C, Mukonka P, Sitwala L, Howard-Hunt B, Notter J. The development of critical care nursing education in Zambia. *Br J Nurs.* (2020) 29:499–505. doi: 10.12968/bjon.2020.29.9.499

22. World Health Organization. *State of the world's nursing 2020: Investing in education, jobs and leadership*. Geneva: World Health Organization (2020).

23. The National Academies Press. *The future of nursing 2020-2030: Charting a path to achieve health equity*. Washington, DC: The National Academies Press (2020).

24. Slusher T, Kiragu A, Day L, Bjorklund A, Shirk A, Johannsen C, et al. Pediatric critical care in resource-limited settings-overview and lessons learned. *Front Pediatr.* (2018) 6:49. doi: 10.3389/fped.2018.00049

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Incidence and predictors of mortality among patients admitted to adult intensive care unit at public hospitals in Western Ethiopia: a retrospective cohort study

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Introduction: In resource-constrained countries, the incidence of mortality among patients admitted to adult intensive care units is higher than that in developed countries, which has a physical, economic, and emotional impact on the lives of patients and their families. However, there is limited evidence on factors related to nursing care that can potentially contribute to predicting and reducing mortality rates in intensive care units. Therefore, this study aimed to assess the incidence of mortality and its predictors in patients admitted to an adult intensive care unit.

Methods: A retrospective cohort study was conducted among 403 patients admitted to the adult intensive care unit from 1 January 2021 to 31 December 2021. The collected data were entered into Epi Data Manager v4.6.0.6 and exported to SPSS version 24 for analysis. Binary logistic regression was used to identify the predictors of mortality. Variables with a *p*-value less than 0.25 in bivariable logistic regression were selected for multivariable logistic regression. A *p*-value <0.05 was used to indicate a significant association in multivariable analysis. Finally, the adjusted relative risk (RR) with 95% CI was calculated.

Results: A total of 403 patients were included in the analysis. The cumulative incidence of death was 40.9% (95% CI 36, 45.9%). Mortality was significantly associated with the need for mechanical ventilation (adjusted RR = 1.45; 95% CI: 1.04, 1.85), the Glasgow Coma Scale score < 8 (adjusted RR, 3.52; 95% CI: 2.90, 4.05), presence of comorbidity (adjusted RR, 1.47; 95% CI: 1.09, 1.83), length of stay in ICU < 24 h (adjusted RR, 1.84; 95% CI: 1.37, 2.04), oxygen saturation level, and Feeding, Analgesia, Sedation, Thrombosis prophylaxis, Head elevation, Ulcer prophylaxis, and Glucose control (FASTHUG) treatment received were significantly associated with mortality.

Conclusion: The study found a high incidence proportion of death. The need for mechanical ventilation, length of stay, comorbidity, and the Glasgow Coma Scale score were significantly associated with mortality. Therefore, close monitoring and evaluation of patients are essential to improve treatment outcomes.

KEYWORDS

ICU, mortality, incidence, predictors, Western Ethiopia

Introduction

An intensive care unit (ICU) is a special hospital or healthcare facility department that provides intensive care treatment to patients with severe or life-threatening illnesses and injuries, which require constant care and close supervision under life support equipment and medication. Intensive care is the specialized treatment given to acutely unwell patients requiring critical medical care (1, 2). By 1953, Bjorn Ibsen, the anesthetist who proposed that positive pressure ventilation be the treatment of choice during the polio epidemic, had constructed Europe's first intensive care unit; many consider him to be the "father" of intensive care (3).

Based on equipment availability and skilled medical and nursing personnel, the World Federation of Societies of Intensive Care Medicine (WFSICCM) classified ICUs into three categories. A level 1 ICU can provide oxygen and non-invasive monitoring, while a level 2 ICU can provide invasive monitoring and basic life support for a limited amount of time. A level 3 ICU offers a comprehensive range of monitoring and life support systems and may contribute to the advancement of intensive care medicine through research and education (4).

ICUs began to develop in many resource-limited countries after decades compared with the industrialized countries. However, the burden of critical illness is especially high in low-income countries as infections such as pneumonia, diarrhea, and malaria are endemic, and traffic accidents, obstetric complications, and surgical emergencies are common (5, 6).

In Ethiopia, the Ministry of Health established an Emergency Medicine and Critical Care Directorate and Implementation Guidelines in 2015 to standardize ICU organization, design, and common practices including rounds, admission, and discharge, reflecting increased attention to emergency medicine and critical care capacity (7). Currently, 53 public hospitals in Ethiopia, provide adult intensive care services (8).

Mortality is a major endpoint in epidemiological and interventional studies conducted in the ICU. Despite medical advances in patient management, ICU mortality remains high as approximately one-third of patients dying in the hospital died in ICU, though the mortality has large variations according to patient case mix and organization of care in ICU (9, 10).

Critically ill patients are admitted to the ICU to reduce morbidity and mortality associated with acute illness, trauma, or surgical procedures (11). Globally, the incidence of death in ICU roughly ranges from 20 to 47% though this magnitude varies between regions and countries (12, 13). It varies across the world depending on the ICU infrastructure, staff availability, training, pattern, and cause of ICU admission.

The incidence of mortality is high in African countries. A retrospective study conducted in Ugandan Mulago Hospital and Kenyan Hospital showed an incidence proportion of mortality of 43.7% (14) and 53.6% (15), respectively. In Ethiopia, studies have indicated poor outcomes for patients admitted to intensive care units with the mortality ranging from 39 to 47% (16–18). ICUs in Addis Ababa faced a high incidence of mortality, 32% of admitted patients to emergency care died (19), and it was 27% in Ayder Hospital (20) and 38.7% in Gondar Hospital (21).

The major causes of ICU admission include trauma, cardiac disease, acute abdominal presentations, septic shock, tetanus, and hysterectomy secondary to uterine rupture. Medical diagnoses accounted for 50.1% of ICU admissions followed by surgery (43.2%) and obstetrics (5.8%) and the corresponding survival rates of the cases were 53.6% for medical admissions, 48.0% for surgery, and 42.9% for obstetrics (22). A shortage of ICU beds, lack of sufficiently trained healthcare professionals, constraints in critical technologies, shortage of medications, scarce data on patient outcomes, immaturity of the program, lack of partnership, and stakeholders are the major challenges of critical care service in developing nations (11, 23).

Morbidity and mortality in the ICU due to critical illness or accident can have a huge physical, social, economic, and emotional impact on the life and family of the admitted patients (24). A study conducted in Malaysia showed that patients who spent a lot of money on treatment had a 2-fold increased risk of dying (25, 26). The influence of death on overall ICU expenses was studied in the United States, and the median observed cost of a unit stay was $9,619 (mean = $16,353). A national study conducted in Scotland demonstrated that ICU survivorship is associated with higher ($25,608 versus $16,913/patient) hospital resource utilization than hospital controls (27). Financial and psychological burdens, shattered family expectations and family integrity, lack of confidence in hospitals' service delivery system, families being immersed in an unfriendly environment, and a sense of fulfillment in helping the patient were among the problems faced in ICUs by patient caregivers, according to a study conducted in Addis Ababa, Ethiopia (28).

The Ethiopian Federal Ministry of Health has shown a renewed commitment to emergency care systems through the development of the Emergency and Critical Care Directorate (ECCD) in its administrative structure. This directorate aimed to reduce unfavorable outcomes in ICUs to less than 25% by 2020 by training emergency physicians and developing out-of-hospital emergency care (7), but the incidence of mortality rate of patients admitted to ICU is still high and far beyond the target.

Despite the incidence of mortality, which is high among patients admitted to the ICU and results in loss of human and economic resources, prior studies only assessed factors associated with sociodemographic and clinical characteristics and did not assess factors associated with care in the ICU. Thus, this study aimed to fill these gaps by assessing the factors associated with mortality among patients admitted to the ICU in Nekemte City public hospitals using a retrospective cohort study method by incorporating factors related to care components.

Methods

Study area

The study was conducted in Western Ethiopian public hospitals on patients admitted to the adult ICU from 1 January 2021 to 31 December 2021. Nekemte Specialized Hospital and Wollega University Referral Hospitals are the two hospitals with adult ICUs in the western part of Ethiopia. The data were collected from 11 April 2022 to 11 May 2022. Wollega University Referral Hospital was

Abbreviations: COPD, Chronic Obstructive Pulmonary Disease; ESV-ICD, Ethiopian Simplified Version of the International Classification of Diseases; FASTHUG, Feeding, Analgesia, Sedation, Thrombosis prophylaxis, Head elevation, Ulcer prophylaxis, Glucose control; GCS, Glasgow Coma Scale; LOS, length of stay.

established in 2017. It serves a catchment population of 3.5 million people. The ICU service provision started in 2018 and was equipped with six beds, four mechanical ventilators, one defibrillator, and one ultrasound machine. One consultant anesthesiologist, two emergency and critical care nurses, six rotating general practitioners, and ten rotating BSc nurses. Nekemte Specialized Hospital serves as a referral center for western Ethiopia, with approximately 11 million people, and ICU service provision was started recently in March 2020 GC. The ICU of the Nekemte Specialized Hospital is equipped with six beds, four mechanical ventilators, two defibrillators, and one ultrasound machine. It was also staffed by one general practitioner, one emergency and critical care nurse, one consultant physiotherapist, and nine rotating BSc nurses.

Study design

An institutional-based retrospective cohort study design was conducted.

Study period

A study was conducted on data of patients admitted to adult ICU at Nekemte Specialized Hospital and Wollega University Referral Hospital from 1 January 2021 to 31 December 2021.

Source population

All patients who were admitted to adult intensive care units at Nekemte City public hospitals.

Study population

Patients who were admitted and registered into the adult ICU at Nekemte Specialized Hospital and Wollega University Referral Hospital from 1 January 2021 to 31 December 2021.

Inclusion criteria

All patients admitted and registered to the adult ICU of Nekemte Specialized Hospital and Wollega University Referral Hospital from 1 January 2021 to 31 December 2021 were included in the study.

Exclusion criteria

Patients whose charts were incomplete, patients whose charts were not found or lost, and patients referred to other higher facilities for better diagnosis and management were excluded from the study.

Sample size determination

The sample size was calculated by using a two or double population proportion formula, and it was calculated through Epi Info version 7 statistical software package with the assumption of confidence level 95% ($Z\alpha/2 = 1.96$), power 80% ($Z1\text{-}\beta = 0.84$), the ratio of unexposed to exposed is 2, and the proportion of outcome in exposed and RR. Independent predictors, such as the presence of sepsis, need for mechanical ventilation, hypoxia, shorter duration of ICU stay, and age greater than 80 years, were considered for sample size calculation. Among these predictors, the primary exposure variable, which was the need for mechanical ventilation, yielded the largest sample size of 414. Therefore, the final sample size of the study was 414.

Sampling procedure

The source population during the specified study period was 473, which is relatively small when compared to the minimum required sample size of 414. Therefore, a census of all patients who were registered and admitted to both ICUs was taken and analyzed. Consequently, 403 patient charts with complete data were included in the analysis (Figure 1).

Data collection tool and procedure

A data extraction checklist was prepared after an extensive literature review and patient charts. It is comprised of three parts: sociodemographic characteristics, related clinical characteristics, and laboratory parameters. Four nurses (two for each hospital) gathered the data under the supervision of two additional BSc Nurses (one for each hospital). The medical registration number of admitted patients from the ICU registry was used to extract patient charts from the chart room. The data collectors completed the checklist by reviewing patient records and charts. Then, the supervisor checked sample data for error and completeness of the data and submitted it to the principal investigator.

Study variables

Dependent variable: status at discharge from ICU (alive or deceased).

Independent variables: the explanatory variables were sociodemographic factors and laboratory-related and clinical factors.

Operational definition

Deceased: those who passed away while in the ICU and given code number 3 on the ICU registry.

Alive: those who survived during ICU stay, including patients who improved and were discharged, and those who left against medical advice (code 1) and were transferred to (code 2).

FASTHUG score: FASTHUG is a shorthand representation for Feeding, Analgesia, Sedation, Thrombosis prophylaxis, Head elevation, Ulcer prophylaxis, and Glucose control. From the patient chart, whether the patient received this routine care was checked and coded 'Yes' if the patient had received that specific treatment, and care, and 'No' if that patient had not received that treatment and care. Finally, all the answers 'yes' were added, and the mean was calculated and yielded 3. Patients were categorized based on their scores as above or below the mean.

Comorbidity: the condition of having two or more diseases at the same time in addition to the main disease with which the patient was admitted to the ICU.

Incomplete data: patient charts with dependent variables were not found, and those with <80% of the variables were found.

Data quality control

A one-day training was given to data collectors and supervisors on the objective of the study, the contents of the checklist, ethical issues, and the data collection approach. To identify the reliability of the data collection instruments, a pre-test was conducted before actual

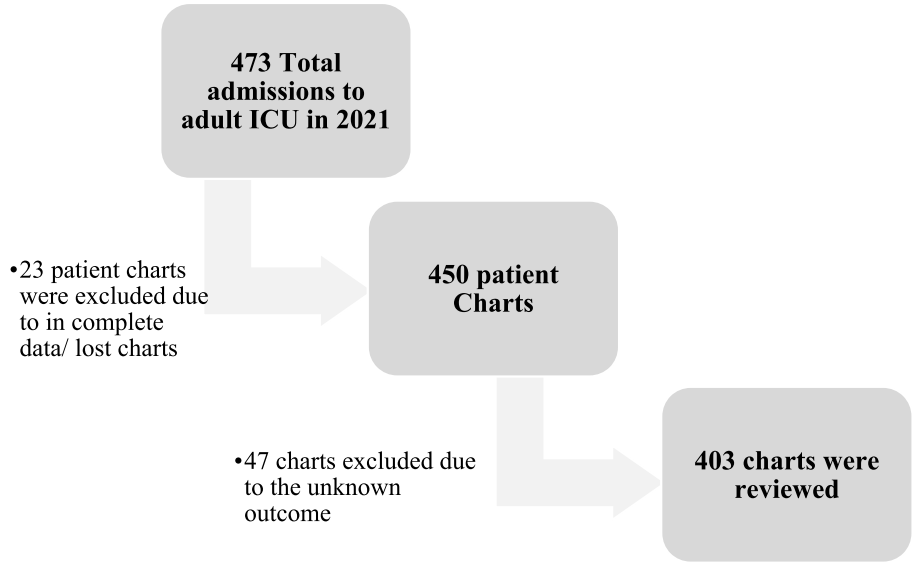

FIGURE 1
Sampling procedure of patient charts, incidence and predictors of mortality among patients admitted to adult ICU, Western Ethiopia, 2021.

data collection, followed by a discussion with data collectors and supervisors, which was modified to enhance the completeness of the data. The supervisors checked the completeness of the checklist at the end of each data collection day.

Data processing and analysis

Data were coded and entered into Epi Data Manager version 4.6.06 and exported to SPSS version 24 for cleaning and analysis. Descriptive statistics, such as frequencies, proportions, and mean with SD and median with IQR, were used to describe the data. Data were organized using tables, graphs, and charts. A binary logistic regression model was used to determine the association between each independent variable and the patient outcome at ICU discharge (29, 30). Variables with a p-value less than 0.25 in bivariable logistic regression were selected for multivariable logistic regression. In the multivariable model, a statistical significance was set at $p < 0.05$. The goodness of fit of the model was checked by the Hosmer–Lemeshow test with a p-value of 0.35, indicating that the model was well fitted, and multicollinearity was checked by VIF; values were below 10. The adjusted odds ratio (AOR) was converted to adjusted relative risk using the Zhang and Yu formula (31), based on the STROBE recommendation (32). Finally, the adjusted relative risk with 95% CI was reported.

Ethics statement

Ethical approval was obtained from the Ethical Clearance Committee of Wollega University in its review held on 15 March 2022 (reference number WU/RD/555/2014). A letter of cooperation was written to the Nekemte Specialized Hospital and Wollega University Referral Hospital. A formal permission letter was written to the Emergency and Critical Care Department and Chart Room Office by the CED of both hospitals, and data were extracted from the patient charts. The need for informed consent was waived by the ethical review committee of Wollega University by the Declaration of Helsinki. In addition, the data collection tool was fully anonymized as it did not contain individual patient identifiers, such as name and Medical Record Numbers, and the authors had no access to the patient identifier.

Result

Socio-demographic characteristics of patients

A total of 403 patients were included in the analysis. The remaining 70 patient charts were excluded because of unknown patient outcomes, lost charts, or incomplete data. The mean (±SD) age of the patients admitted to adult ICU was 41 (17) years. The age category greater than 55 years constituted more admissions (28.3%), and the mortality rate was relatively high (45.2%) among the age category of 35–44 years. Of the total study participants, 221 (54.8%) were men, and 240 (59.6%) were from rural residents (Table 1).

Clinical characteristics of the patients

Admission diagnosis and disease category

Cardiovascular diseases were the most common underlying cause of ICU admission accounting for 110 (27.3%) followed by diseases of the respiratory system which contributed 79 (19.6%). The death rate was high among patients admitted with endocrine, nutritional, and metabolic diseases, of which 17 (61%) died, followed by infectious and parasitic diseases, in which 35 (54%) died (Table 2).

TABLE 1 Socio-demographic characteristics of patients admitted to adult ICU, Western Ethiopia, 2021.

Characteristics category		Status		Total	
		Deceased N = 165	Alive N = 238	Count N = 403	%
		Count	Count		
Age category	15–24	32	48	80	20
	25–34	30	51	81	20
	35–44	28	34	62	15
	45–54	28	38	66	16
	>=55	47	67	114	28
Sex	Male	96	125	221	55
	Female	69	113	182	45
Residence	Rural	94	146	240	60
	Urban	71	92	163	40

TABLE 2 Underlying causes of admission to adult IC, Western Ethiopia, 2021.

ESV-ICD-11 chapters	Patient status at discharge from ICU			
	Alive		Deceased	
	Count	%	Count	%
Infectious and parasitic diseases	30	46.2%	35	53.8%
Neoplasms	7	77.8%	2	22.2%
Endocrine, nutritional, or metabolic diseases	11	39.3%	17	60.7%
Diseases of the nervous system	10	76.9%	3	23.1%
Diseases of the circulatory system	75	68.2%	35	31.8%
Diseases of the respiratory system	50	63.3%	29	36.7%
Diseases of the digestive system	16	57.1%	12	42.9%
Pregnancy, childbirth, or the puerperium	9	52.9%	8	47.1%
Injury, poisoning, or certain other consequences of external causes	30	55.6%	24	44.4%
Total	238	59.1%	165	40.9%

Comorbidity status, source of admission, and other clinical characteristics

The study also showed that 149 (37%) patients had at least one comorbid disease, with hypertension being the most common (59, 15%), followed by diabetes mellitus (all types 19; 4%), acute and chronic kidney disease (18, 4.5%), and pneumonia (17, 4.2%). Among all admissions, 327 (81.1%) were for medical reasons, and the mortality rate was 41% in this group.

This study revealed that the median length of stay in the ICU was 72 h (IQR = 96 h). Of the patients, 285 (70.7%) stayed longer than 24 h, and 118 (29.3%) stayed for less than 24 h in ICU. Of patients who stayed less than 24 h in the ICU, 74 (62.7%) and 91 (31.9%) of patients who stayed for longer than 24 h died in ICU.

One hundred fifty-seven (39%) patients were referred from other health facilities (had referral forms), while others were self-referrals. Regarding the time of admission to the ICU, 297 (74%) patients were admitted during regular working days and the remaining 106 (26%) were admitted during weekends and holidays.

Vital signs and care-related characteristics

At admission, 195 (48.4%) patients had a normal respiratory rate of 12–20 breaths per minute, whereas 208 (51.6%) patients had unstable respiration of less than 12 or greater than 20 breaths per minute. The incidence proportion of mortality rates was 83 (42.6%) and 82 (39.4%) in patients with normal and deteriorated respiratory rates, respectively. Blood pressure measurement was another vital sign measured at admission to ICU; 110 (27.3%) patients were normotensive (90–140 mmHg), while 293 (72.7%) patients were either hypotensive or hypertensive. One hundred and one patients (25%) required mechanical ventilation on admission to the ICU, of whom 59 (58.4%) died, and 106 (35.1%) died among those who were not on mechanical ventilation (Table 3).

This study showed that 396 (98.3%) patients had received at least one component of FASTHUG treatment, and 52 (12.9%) patients received all seven components. Glucose control was the most treatment provided 367 (91.1%) followed by anti-pain provision 356 (88.3%) and ulcer prophylaxis 315 (78.2%) (Figures 1, 2).

TABLE 3 Vital signs and related parameters among patients admitted to adult ICU, Western Ethiopia, 2021.

Characteristics	Patient status at discharge from ICU						
	Deceased			Alive		Total	
	Category	Count	%	Count	%	Count	%
Mechanical ventilation?	Yes	59	58.4	42	41.6	101	25.1
	No	106	35.1	196	64.9	302	74.9
Oxygen saturation	<90	101	49.3	104	50.7	205	50.9
	>=90	64	32.3	134	67.7	198	49.1
Sepsis	Yes	39	53.4	34	46.6	73	18.1
	No	126	38.2	204	61.8	330	81.9
Glasgow Coma Scale score	< 8	122	68.2	57	31.8	179	44.4
	9–12	23	21.3	85	78.7	108	26.8
	13–15	20	17.2	96	82.8	116	28.8
BP measurement at admission	Hypotensive	40	55.6	32	44.4	72	17.9
	Normal	47	42.7	63	57.3	110	27.3
	Hypertensive	78	35.3	143	64.7	221	54.8
Respiratory rate at admission per minute	12–20	83	42.6	112	57.4	195	48.4
	< 12	4	66.7	2	33.3	6	1.5
	> 20	78	38.6	124	61.4	202	50.1
Pulse rate category	< 60	7	50.0	7	50.0	14	3.5
	60–100	101	39.8	153	60.2	254	63.0
	> 100	57	42.2	78	57.8	135	33.5
Hemoglobin count in g/dl	< 13	111	40.5	163	59.5	274	68.0
	> 13	54	41.9	75	58.1	129	32.0
FASTHUG category	0–3	59	62.8	35	37.2	94	23.3
	4–7	106	34.3	203	65.7	309	76.7

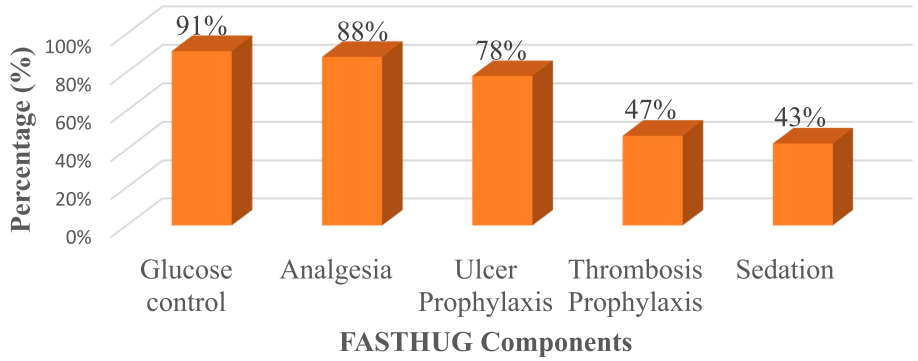

FIGURE 2
Frequency of FASTHUG treatment components among patients admitted to adult ICU; Western Ethiopia, 2021.

Incidence and predictors of mortality in ICU

A total of 403 patients were retrospectively followed up until discharge from ICU. The incidence proportion of mortality in ICU was 40.9% (95% CI: 36.1–45.9%) in 1 year.

Eighteen variables were tested for their association with mortality at ICU discharge. In the bivariable analysis, variables such as the need for mechanical ventilation, comorbidity, length of stay in ICU, GCS, sepsis, deteriorated BP, oxygen saturation level, and FASTHUG score were significant at a *p*-value <0.25 and were selected for multivariable logistic regression at *p* value <0.25 (Table 5).

However, in the multivariable analysis, only the need for mechanical ventilation, presence of comorbidity, length of stay in the ICU, GCS, oxygen saturation level, and FASTHUG score remained statistically significant. The prediction ability of the model was checked using the area under the receiver operating characteristic curve. The area under receiver operating characteristics value was 8.853 (95% CI: 0.853, 0.889).

Patients who were on mechanical ventilation were 1.45 times more likely to die than those who were not on mechanical support (adjusted RR = 1.45, 95% CI: 1.04, 1.85). The length of stay in the ICU was another strong predictor of ICU mortality. This study showed that patients who stayed for less than 24 h were 1.84 times more likely to die than patients who stayed for longer than 24 h (adjusted RR = 1.84, 95% CI: 1.37, 2.04). This study showed that there is an inverse association between the GCS score and the risk of death in patients admitted to the ICU. Patients with a GCS of <8 were 3.52 times at risk of death in the ICU compared to those with a score greater than or equal to 9 GCS score (adjusted RR = 3.52, 95% CI: 2.90, 4.05).

Patients whose oxygen saturation of less than 90% by pulse oximetry were 1.4 times more likely to die than those with oxygen saturation greater than 90% (adjusted RR = 1.40, 95% CI: 1.03, 1.79).

Patients receiving less or equal to three components of the FASTHUG care are found to be 1.6 times at higher risk of death than those receiving four or more care components (adjusted RR, 1.60; 95% CI: 1.16, 2.01). Patients with one or more comorbidities had 1.47 times more chance of dying (Table 4).

Discussion

The incidence proportion of mortality in this study was found to be comparable with the results of a study conducted in Hosanna, Gondar University, St. Paul's Hospital, and Mulago Hospital of Uganda, which reported a mortality incidence proportion of 46.2% (16), 38.7% (21), 39% (18), and 43.7% (14), respectively. However, it was found to be lower than the result of a study conducted in Southern Ethiopia hospitals and Kenya, which reported a mortality rate of 46.8% (17) and 53.6% (15), respectively. This discrepancy might be due to the difference in admission diagnosis in which 54–80% of patients admitted in Southern Ethiopia and Western Kenyan hospitals presented with acute respiratory distress syndrome requiring respiratory support compared to the 25% in this study. This is not surprising that acute respiratory failure and acute respiratory distress syndrome are drivers of high mortality (33). The difference in the level of ICU care provided, which can be explained by differences in ICU equipment, healthcare professionals, and availability of medications could also contribute to the observed discrepancy in mortality rates between hospitals.

It is not a surprise that the incidence proportion of mortality in the current study is much higher than the finding of the study conducted in resource-affluent countries. The study conducted in Brazil reported 21% (34), and a multicenter European cohort study reported 19.1% (35). This huge discrepancy might be due to the difference in the level of ICU care, availability of medical supplies, availability of trained staff, and the use of high-cost technologies.

In this study, patients who required mechanical ventilation were more likely to die than those who were not. This finding is in line with the findings of a study conducted in Gondar (21), Kenya (15), and Brazil (34). Patients with respiratory distress are more unstable and susceptible to ventilator-associated pneumonia and other nosocomial infections, posing a risk to their clinical prognosis (36).

The Glasgow Coma Scale score was another predictor of mortality for patients in the ICU. Patients with a GCS score of <8 were more

TABLE 4 Multivariable logistic regression analysis of predictors of mortality among patients admitted to adult ICU, Western Ethiopia, 2021.

Characteristics	Category	Status		Crude RR (95% CI)	Adjusted RR (95% CI)
		Deceased	Alive		
		165	238		
Mechanical ventilation	Yes	59	42	1.66 (1.34, 1.97)	1.45 (1.04–1.85)*
	No	106	196	1	1
Comorbidity	Yes	74	75	1.39 (1.10, 1.67)	1.47 (1.09–1.83)**
	No	91	163	1	1
Peripheral Oxygen saturation	< 90%	101	104	1.35 (1.15, 1.52)	1.40 (1.03–1.79)*
	> = 90%	64	134	1	1
Sepsis	Yes	39	34	1.40 (1.07, 1.72)	1.38 (0.95–1.79)
	No	126	204	1	1
Length of stay in hours	< 24 h	74	44	1.96 (1.62, 2.27)	1.84 (1.37–2.04)***
	>24 h	91	194	1	1
BP in mmHg	Normal	47	63	1	1
	Hypotensive	40	32	1.48 (1.17, 1.75)	1.36 (0.97–1.71)
	Hypertension	78	143	1.18 (0.91, 1.45)	1.05 (0.71–1.42)
GCS Score	< = 8	122	57	3.55 (3.00, 4.02)	3.52 (2.90–4.05)***
	> 9	43	181	1	1
FASTHUG care score	0–3	59	35	1.83 (1.49, 2.13)	1.60 (1.16–2.01)**
	4–7	106	203	1	1

***p-value < 0.00; **p-value < 0.01; *p-value < 0.05; 1, reference; BP, blood pressure; GCS, Glasgow Coma Scale.

TABLE 5 Bivariable logistic regression analysis of predictors of mortality among patients admitted to adult ICU, Western Ethiopia, 2021.

Variables	Category	Status			
		Deceased	Alive	*p* Value	COR with 95%CI
Age	15–24	48	32	0.901	1
	25–34	51	30	0.864	0.95 (0.53, 1.70)
	35–44	34	28	0.555	0.84 (0.47, 1.51)
	45–54	38	28	0.614	1.17 (0.63, 2.19)
	>=55	67	47	0.875	1.05 (0.57, 1.94)
Sex	Male	125	96	1.000	1
	Female	113	69	0.262	1.28 (0.84, 1.88)
Residence	Rural	146	94	0.379	1
	Urban	92	71		1.19 (0.80, 1.80)
HIV status	Negative	219	146	0.467	1
	Positive	6	7	0.323	1.75 (0.57, 5.31)
	Unknown	13	12	0.432	1.38 (0.62, 3.12)
Mechanical ventilation	Yes	42	59	**< 0.001***	2.60 (1.64, 4.12)
	No	196	106	1	1
LOS	< 24 hours	74	44	1.96 (1.62, 2.27)	1.84 (1.37–2.04)***
	> 24 hours	91	194	1	1
GCS	<= 8	57	122	**0.001***	9.01 (5.70, 14.24)
	> 9	181	43	1	1
Comorbidity	Yes	75	74	**0.001***	1.77 (1.17, 2.67)
	No	163	91	1	1
Pulse rate	< 60	7	7	1	1
	60–100	153	101	0.577	1.37 (0.46, 4.12)
	> 100	78	57	0.638	0.90 (0.59, 1.38)
Systolic BP	< 90	32	40	.010	1
	90–140	63	47	**0.003***	2.29 (1.34, 3.94)
	> 140	143	78	0.189	1.37 (0.86, 2.18)
Respiratory rate per minute	< 12	2	4	0.339	1
	> 20	124	78	0.258	2.70 (0.48, 15.01)
	12–20	112	83	0.423	0.85 (0.57, 1.27)
Peripheral oxygen saturation	< 90	104	101	**0.001***	2.03 (1.36, 3.05)
	>= 90	134	64	1.000	1
Sepsis	Yes	34	39	**0.018***	1.86 (1.11, 3.10)
	No	204	126		1
The service unit from which the patient was admitted to ICU	Medical Ward	95	68	0.597	1
	Surgical Ward	26	15	0.855	0.96 (0.63, 1.48)
	Gyne Obs Ward	15	6	0.475	0.77 (0.38, 1.56)
	Emergency OPD	102	76	0.219	0.54 (0.20, 1.45)
Frequency of admission	New	232	162	0.640	1.40 (0.34, 5.67)
	Repeat	6	3		1
Anemia	Yes	75	54	0.797	1.60 (0.69, 1.62)
	No	163	111		1
FASTHUG components	<=3	35	59	**0.001***	3.23 (2.00, 5.22)
	> 3	203	106		1
Time of admission to ICU	Working days	178	119		1
	Weekend and Holidays	60	46	0.550	1.15 (0.73, 1.80)

*Variables significant at *p* value <0.25; The symbol ** indicates the the *p* value of < 0.001; 1-Reference. The bold values indicate variables with *p* value less than 0.25 and candidates for multivariable analysis.

likely to die than patients with a GCS score of > = 9. This finding is similar to the finding of a study conducted in Southern Ethiopia (17), Gondar (21), and Mulago Hospital of Uganda (14). This can be explained by the fact that GCS is a significant indicator of disease severity and individuals who have suffered a head injury or other traumas are likely to have lower GCS scores (37).

Oxygen saturation level below 90% is also a predictor of death among ICU patients. This finding is similar to the finding of a study conducted in Peru and France (38, 39). Hypoxemia leads to respiratory distress syndrome due to low hemoglobin concentration in the blood. Patients may have to wait longer for ICU admission due to resource limitations and delayed hospital arrival (40).

This study also revealed that the likelihood of death decreases as the length of hospital stay increases. This finding is in agreement with a study conducted in different parts of the world (41–43). The probable cause of these early fatalities is most likely due to a late presentation to care after potential complications are developed and delayed referral from another health facility. In contrast to this study, a prospective investigation done in Turkey failed to discover a link between the length of time spent in the intensive care unit and the risk of death (42). This is due to the Turkish study's exclusion of patients who spent less than 48 h in an intensive care unit, a period associated with a higher risk of mortality in this study.

This study found that patients who have at least one comorbidity were more likely to die than those who did not have comorbidity. This finding is consistent with the study done in West Scotland the UK (44). This can be explained by the fact that patients with comorbidities show higher Charlson Comorbidity Index and are older age patients, which are, in turn, statistically associated with mortality in the ICU (45).

FASTHUG-based care enables critically ill patients to receive holistic care that encompasses all critical issues and is proven effective in preventing adverse outcomes. This study showed that patients who had received less than three of the seven FASTHUG care components were more likely to die than those who had received at least four components of care. A comparative study conducted in Mexico and the United States revealed that the application of the FASTHUG bundle of care decreased mortality rate (46) and ventilator-associated pneumonia (47), respectively. This suggests that the nursing care model developed is effective in increasing the quality of nursing care given to critically ill patients.

Limitations of the study

Due to the retrospective nature of the study, a limited number of variables were found; as a result, some variables like severity scores (such as APACHE II and SOFA scores) of the patients could not be found, which might have a significant association with mortality of patients admitted to ICU. This mortality incidence is not disease-specific and includes a variety of disease entities that may each have a variable mortality rate. In addition to this, factors associated with ICU resources, staffing, and training status of the staff were not assessed by this study as these factors might have an impact on the outcome of the patients.

The study followed the patients only until their discharge from the ICU and considered patients who were transferred to wards and those left against medical advice as if they were survived or alive. These patients may die after discharge, which may underestimate the incidence of mortality.

Conclusion and recommendations

This study found a high incidence of mortality among patients admitted to the adult ICU. The severity of the condition, which is determined by the GCS score, need for mechanical ventilation, oxygen saturation level, and comorbidity significantly predict mortality among patients admitted to ICU. Patients who require mechanical ventilation were at higher risk of death because these patients were at risk of developing ventilator-associated pneumonia and the limited availability of mechanical ventilators. In addition, it can be due to poor quality of care, which is observed in the number of FASTHUG care. Hospitals should use severity scores (such as APACHE, SAPS II, and SOFA) as a crucial component at the ICU for improving clinical decisions and identifying patients with higher unexpected outcomes. Healthcare providers should also prioritize and give due attention to acutely ill patients like those with respiratory failure, lower GCS scores, and comorbidities. The application of standardized treatment protocols such as the FASTHUG bundle of care should also encouraged and applied regularly as it improves the quality of care and the favorable clinical outcomes. Future investigators should conduct a prospective follow-up study by including important variables such as severity scores and variables related to human resources, equipment, and quality of care.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Ethical clearance obtained from the Ethical Clearance Committee of Wollega University. The studies were conducted by the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin because the study was retrospective, and it was a card review.

Author contributions

FK: Conceptualization, Software, Supervision, Visualization, Writing – original draft, Writing – review & editing, Data curation, Formal analysis, Investigation, Methodology. GM: Conceptualization, Software, Supervision, Visualization, Writing – original draft, Writing – review & editing, Validation. MY: Conceptualization, Formal analysis, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

1. Smith SE. What is an ICU? wiseGEEK (2013); Available at: http://www.wisegeek.com/what-is-an-icu.htm

2. Marshall JC, Bosco L, Adhikari NK, Connolly B, Diaz JV, Dorman T, et al. 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*. (2017) 37:270–6. doi: 10.1016/j.jcrc.2016.07.015

3. Kelly FE, Fong K, Hirsch N, Nolan JP. Intensive care medicine is 60 years old: the history and future of the intensive care unit. *Clin Med*. (2017) 14:376–9. doi: 10.7861/clinmedicine.14-4-376

4. Units IC, Island N, Icus W, Medicine CC, Icu A. What is an ICU? *WFSICCM Reports*. (2014), 2–3.

5. Dünser MW, Baelani I, Ganbold L. A review and analysis of intensive care medicine in the least developed countries. *Crit Care Med*. (2006) 34:1234–42. doi: 10.1097/01.CCM.0000208360.70835.87

6. Baker T. Critical care in low-income countries. *Trop Med Int Heal*. (2009) 14:143–8. doi: 10.1111/j.1365-3156.2008.02202.x

7. Firew T, Gebreyesus A, Woldeyohannes L, Ebrahim F, Patel S. Human resources for emergency care systems in Ethiopia: challenges and triumphs. *African J Emerg Med*. (2020) 10:S50–5. doi: 10.1016/j.afjem.2020.09.006

8. Kifle F, Boru Y, Tamiru HD, Sultan M, Walelign Y, Demelash A, et al. Intensive Care in sub-Saharan Africa: a National Review of the service status in Ethiopia. *Anesth Analg*. (2021):1–8. doi: 10.1213/ANE.0000000000005799

9. Ay E, Weigand MA, Röhrig R, Gruss M. Dying in the intensive care unit (ICU): a retrospective descriptive analysis of deaths in the ICU in a communal tertiary Hospital in Germany. *Anesthesiol Res Pract*. (2020) 2020:1–10. doi: 10.1155/2020/2356019

10. Orban JC, Walrave Y, Mongardon N, Allaouchiche B, Argaud L, Aubrun F, et al. Causes and characteristics of death in intensive care Units. *Anesthesiology*. (2017) 126:882–9. doi: 10.1097/ALN.0000000000001612

11. Rn ME, Carter Rn LW, Rn KP, Vincent S. Factors associated with in-hospital mortality following ICU discharge: a comprehensive review. (2012);120–125.

12. Colpan A, Akinci E, Erbay A, Balaban N, Bodur H. Evaluation of risk factors for mortality in intensive care units: a prospective study from a referral hospital in Turkey. *Am J Infect Control*. (2017) 33:42–7. doi: 10.1016/j.ajic.2004.09.005

13. Du B, An Y, Kang Y, Yu X, Zhao M, Ma X, et al. Characteristics of critically ill patients in ICUs in mainland China. *Crit Care Med*. (2013) 41:84–92. doi: 10.1097/CCM.0b013e31826a4082

14. C44. Critical Illness Predictors and Outcomes. Mortality rate and associated factors among intensive care unit patients at Mulago hospital, Uganda: a prospective cohort study (2022). Available at: https://www.atsjournals.org/doi/abs/10.1164/ajrccm-conference.2014.189.1_MeetingAbstracts.A4521

15. Lalani HS, Waweru-Siika W, Mwogi T, Kituyi P, Egger JR, Park LP, et al. Intensive care outcomes and mortality prediction at a National Referral Hospital in Western Kenya. *Ann Am Thorac Soc*. (2018) 15:1336–43. doi: 10.1513/AnnalsATS.201801-051OC

16. Mohammed SO, Abdi OA, Getish BG. Clinical outcomes of patients admitted in intensive care units of Nigist Eleni Mohammed memorial Hospital of Hosanna, southern Ethiopia. *Int J Med Med Sci*. (2017) 9:79–85. doi: 10.5897/IJMMS2017.1297

17. Abate SM, Assen S, Yinges M, Basu B. Survival and predictors of mortality among patients admitted to the intensive care units in southern Ethiopia: a multi-center cohort study. *Ann Med Surg*. (2021) 65:102318. doi: 10.1016/j.amsu.2021.102318

18. Kedir S, Berhane A, Bayisa T, Wuletaw T. Admission patterns and outcomes in the medical intensive care unit of St. Paul's hospital millennium medical college, Addis Ababa, Ethiopia. *Ethiop Med J*. (2017) 55:19–26.

19. Sultan M, Mengistu G, Debebe F, Azazh A, Trehan I. The burden on emergency centers to provide care for critically ill patients in Addis Ababa, Ethiopia. *African J Emerg Med*. (2018) 8:150–4. doi: 10.1016/j.afjem.2018.07.006

20. Gidey K, Abraha HA. Pattern and outcome of medical intensive care unit admission to Ayder Càmprehensive specialised hospitalised Hospital in Tigray, Etiopia. *Ethiop Med J*. (2018) 56:31–6.

21. Tessema HG, Lema GF, Mesfin N, Fentie DY, Arefaynie NR. Admission pattern, clinical outcomes, and associated factors among patients admitted in medical intensive care unit at University of Gondar Comprehensive and Specialized Hospital, Northwest Ethiopia, 2019. A retrospective cross-sectional study (2019):1–23. doi: 10.21203/rs.2.13346/v1,

22. Smith ZA, Ayele Y, McDonald P. Outcomes in critical care delivery at Jimma University specialised hospital. *Ethiopia Anaesth Intensive Care*. (2013) 41:363–8. doi: 10.1177/0310057X1304100314

23. Schultz MJ, Dunser MW, Dondorp AM, Adhikari NKJ, Iyer S, Kwizera A, et al. Current challenges in the management of sepsis in ICUs in resource-poor settings and suggestions for the future. *Intensive Care Med*. (2017) 43:612–24. doi: 10.1007/s00134-017-4750-z

24. Intensive care units (ICUs). (2021). Available at: https://www.healthywa.wa.gov.au/Articles/F_I/Intensive-care-units-ICUs

25. Aung YN, Nur AM, Ismail A, Aljunid SM. Characteristics and outcome of high-cost ICU patients. *Clin Outcomes Res*. (2019) 11:505–13. doi: 10.2147/CEOR.S209108

26. McLaughlin AM, Hardt J, Canavan JB, Donnelly MB. Determining the economic cost of ICU treatment: a prospective "micro-costing" study. *Intensive Care Med*. (2017) 35:2135–40. doi: 10.1007/s00134-009-1622-1

27. Lone NI, Gillies MA, Haddow C, Dobbie R, Rowan KM, Wild SH, et al. Five-year mortality and hospital costs associated with surviving intensive care. *Am J Respir Crit Care Med*. (2016) 194:198–208. doi: 10.1164/rccm.201511-2234OC

28. Kehali H, Berhane Y, Gize A. A phenomenological study on the lived experiences of families of ICU patients, Addis Ababa, Ethiopia. *PLoS One*. (2020) 15:e0244073. doi: 10.1371/journal.pone.0244073

29. Sprent P. An Introduction to categorical data analysis. *J R Stat Soc A Stat Soc*. (2007) 170:1178–8. doi: 10.1111/j.1467-985X.2007.00506_2.x

30. Scott AJ, Hosmer DW, Lemeshow S. Applied Logistic Regression. *Biometrics*. (1991) 47:1632

31. Zhang J, Yu KF. What's the relative risk? A method of correcting the odds ratio in cohort studies of common outcomes. *JAMA J Am Med Assoc*. (1998) 280:1690–1. doi: 10.1001/jama.280.19.1690

32. von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. STROBE eigen doc (from the Equator) (2008) 1:12–3. Available at: http://www.epidem.com/

33. Summers C, Singh NR, Worpole L, Simmonds R, Babar J, Condliffe AM, et al. Incidence and recognition of acute respiratory distress syndrome in a UK intensive care unit. *Thorax*. (2016) 71:1050–1. doi: 10.1136/thoraxjnl-2016-208402

34. Pinheiro FGDMS, Santos ES, Barreto DDC, Weiss C, Vaez AC, Oliveira JC, et al. Mortality predictors and associated factors in patients in the intensive care unit: a cross-sectional study. *Crit Care Res Prac*. (2020) 2020:1–6. doi: 10.1155/2020/1483827

35. Capuzzo M, Volta CA, Tassinati T, Moreno RP, Valentin A, Guidet B, et al. Hospital mortality of adults admitted to intensive care units in hospitals with and without

intermediate care units: a multicentre European cohort study. *Crit Care*. (2014) 18:1–15. doi: 10.1186/s13054-014-0551-8

36. Papazian L, Klompas M, Luyt CE. Ventilator-associated pneumonia in adults: a narrative review. *Intensive Care Med*. (2020) 46:888–906. doi: 10.1007/s00134-020-05980-0

37. Weingarten S, Bolus R, Riedinger MS, Maldonado L, Stein S, Ellrodt AG. The principle of parsimony: the Glasgow coma scale score predicts mortality as well as the Apache II score for stroke patients. *Stroke*. (1990) 21:1280–2. doi: 10.1161/01.STR.21.9.1280

38. Grimaldi D, Hraiech S, Boutin E, Lacherade JC, Boissier F, Pham T, et al. Hypoxemia in the ICU: prevalence, treatment, and outcome. *Ann Intensive Care*. (2018) 8: 8–9. doi: 10.1186/s13613-018-0424-4

39. Mejía F, Medina C, Cornejo E, Morello E, Vásquez S, Alave J, et al. Oxygen saturation as a predictor of mortality in hospitalized adult patients with COVID-19 in a public hospital in Lima, Peru. *PLoS One*. (2020) 15:1–12. doi: 10.1371/journal.pone.0244171

40. Flenley DC. Respiratory failure. *Scott Med J*. (1970) 15:61–72. doi: 10.1177/00369 3307001500205

41. Kwizera A, Dünser M, Nakibuuka J. National intensive care unit bed capacity and ICU patient characteristics in a low-income country. *BMC Res Notes*. (2012) 5:4–6. doi: 10.1186/1756-0500-5-475

42. Unal AU. Prognosis of patients in a medical intensive care unit. *North Clin Istanbul*. (2016) 2:189–95. doi: 10.14744/nci.2015.79188

43. MedskEDSK E, Khani Y, Hashemi-Nazari SS, Izadi N, Eshrati B, Mehrabi Y. Survival rate in patients with ICU-acquired infections and its related factors in Iran's hospitals. *BMC Public Health*. (2021) 21:1–9.

44. Simpson A, Puxty K, McLoone P, Quasim T, Sloan B, Morrison DS. Comorbidity and survival after admission to the intensive care unit: a population-based study of 41,230 patients. *J Intensive Care Soc*. (2021) 22:143–51. doi: 10.1177/1751143720914229

45. El-Adawy A, Khafagy M, El Adawi N, Bahgat M, El-Gilany AH. Intensive care morbidity and mortality and their associated factors: a National Study in Egypt. *Benha Med J*. (2021) 39:52. doi: 10.21608/bmfj.2021.62776.1383

46. Barrera JB, Correa JC, Ruiz MLAMR. Application of the FAST-HUG protocol and its association with the mortality of the critical patient in the ICU. *Medicina Crítica*. (2018):130–8.

47. Papadimos TJ, Hensley SJ, Duggan JM, Khuder SA, Borst MJ, Fath JJ, et al. Implementation of the "FASTHUG" concept decreases the incidence of ventilator-associated pneumonia in a surgical intensive care unit. *Patient Saf Surg*. (2008) 2:3–6. doi: 10.1186/1754-9493-2-3

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Strengthening nursing knowledge and skills in perioperative cleft care: a focused training approach in Nigeria's surgical healthcare plan

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Background: Safe perioperative nursing care is crucial to improving outcomes of surgical care. This is a report on the pilot implementation of a nursing training programme aimed at strengthening safe perioperative nursing care in Nigeria, aligning with the nation's strategic framework for surgical, obstetric, anaesthesia, and nursing plan. The aim of this report is to highlight the need to incorporate perioperative nursing training into efforts to scale up access to surgical care in low resource settings.

Methods: The Nursing Care Saves Lives (NCSL) training programme which was designed for training in perioperative nursing of cleft lip and palate patients, was adapted for perioperative nursing training. A 5-day intensive training was deployed, involving lectures, hands-on activities, simulations, and group problem-solving exercises. Pre- and post-training surveys were administered, and participant feedback and 3-months follow-up assessments obtained. The data has been analysed using descriptive statistics.

Results: Twenty-six participants who were nurses involved in perioperative care, from both public and private hospitals, completed the training. Pre-training evaluation scores ranged from 23 to 72% (median 68%), increasing significantly to 61–98% (median 76%) post-training (p = 0.0001). Participants rated all training contents as useful, with high satisfaction in neonatal resuscitation and basic life support skills. Infection prevention and control, helping babies breathe, and effective communication were identified as key learnings. Recommendations for future training included facilitation skills, nutrition, and research. Although 10 (40%) participants organised step down trainings, limited funding and training materials were key barriers to step down.

Conclusion: The NCSL training programme has the potential for promoting and strengthening safe perioperative nursing care. Strategic efforts are needed to scale up and expand access to this training within the wider perioperative nursing community, to enhance patient safety and surgical outcomes in the setting.

KEYWORDS
surgery, safety, outcomes, perioperative, nursing, training

Introduction

In Nigeria, ensuring safe perioperative nursing care remains a critical priority within the broader context of advancing healthcare delivery. Nursing training in the country is regulated by the Nursing and Midwifery Council of Nigeria (NMCN), with perioperative nursing offered as a post-basic specialization. However, there is a shortage of trained perioperative nurses, particularly in district and general hospitals. Most nurses working at these hospitals have not gone through the post-basic specialisation in perioperative nursing. In addition, paediatric perioperative nursing is not well integrated into the training of these nurses. Further, access to hands-on training, simulation, and continuous professional development in these aspects are limited.

There are important gaps in paediatric perioperative nursing care in the setting. Many nurses lack specialized training in recognizing early post-surgical complications, and standards of care protocols and checklists are not usually in use outside tertiary hospitals. It has been shown that continuing nursing education in low- and middle-income countries is effective in improving their knowledge, and hence patient outcomes and quality of care (1).

Recognizing the pivotal role of nursing in perioperative settings, the implementation of comprehensive training programmes becomes imperative to enhance positive patient outcomes and mitigate risks associated with surgical interventions. Moreover, the outcome of cleft surgery depends on both surgical expertise and quality of postoperative nursing care. Inadequate perioperative nursing care can lead to airway problems and wound complications following cleft surgery.

The Nursing Care Saves Lives (NCSL) training programme is a meticulously designed curriculum crafted to improve the safety and effectiveness of post-operative nursing care for children following cleft surgery (2). Rooted in evidence-based practices and tailored to local contexts, this programme is a holistic approach encompassing theoretical knowledge, practical skills development, and attitudinal enhancements necessary for delivering optimal perioperative care. The course has already been deployed by Smile Train but being piloted by Nigeria's NSOANP. There is presently no published data on previous pilots and evaluation of the programme.

This manuscript presents a report on the pilot implementation of the nursing training programme tailored to strengthen safe perioperative care in Nigeria. This aligns with the nation's strategic framework for surgical, obstetric, anaesthesia, and nursing services (3). The report is intended to highlight the feasibility and potential impact of this training and application to similar settings.

Methods

Nursing Care Saves Lives (NCSL) is a 5-day training programme designed by Smile Train (a cleft lip and palate focused organisation that supports the delivery of free surgery to cleft patients) provides nurses with essential skills needed to safely administer pre- and post-operative nursing care for patients with cleft lip and palate. The curriculum involves lectures and didactic instruction, while also incorporating interaction between trainer and trainees. Participants practice essential skills such as infant resuscitation, patient monitoring, skill-building exercises, simulation of scenarios, and group problem solving centred on four pillars of patient assessment, post-operative nursing care, postoperative complications, and post-operative nursing interventions. Particular attention is given to early recognition of post-operative complications and essential nurse-initiated actions. The existing NCSL curriculum (2) was slightly modified to include helping babies breathe (HBB), pulse oximetry, cleft nutrition, and infection prevention and control. Although the NCSL was designed for cleft care, it was adapted to apply to safe perioperative nursing care in general to meet local needs.

Training objectives

The training was done as part of the ongoing implementation of the national surgical, obstetrics, anaesthesia, and nursing plan (NSOANP) in alignment with one of the key objectives of strengthening perioperative nursing care in Nigeria (Figure 1).

Participants

Four participants each from the 6 geopolitical zones of Nigeria, and 2 from the federal capital territory were selected for the training based on their performance in a web-based quiz. The aim of the quiz was to select 25 participants as recommended by the NCSL curriculum, to ensure hands-on experience and involvement of all participants (2). A total of 26 participants were eventually selected for the training. The selected participants were registered nurses involved in perioperative care.

Deployment of training

The training took place in August 2021. This was a 5-day, intensive training attended by the 26 previously selected participants. Activities carried out to ensure effective learning experiences and skills acquisition, included:

1. Team quizzes.
2. Group-based care planning.
3. Problem-solving and group feedback.
4. Hands-on activities using medium fidelity feedback mannequins.
5. Action planning using flip charts and wall charts.

Training evaluation

Pre- and post- training evaluations were administered to the participants to test their knowledge before and after the training. In addition, post training feedback survey was administered to the participants using a 5-point Likert scale. The participants were also followed up for 3 months to evaluate the early impact of the training.

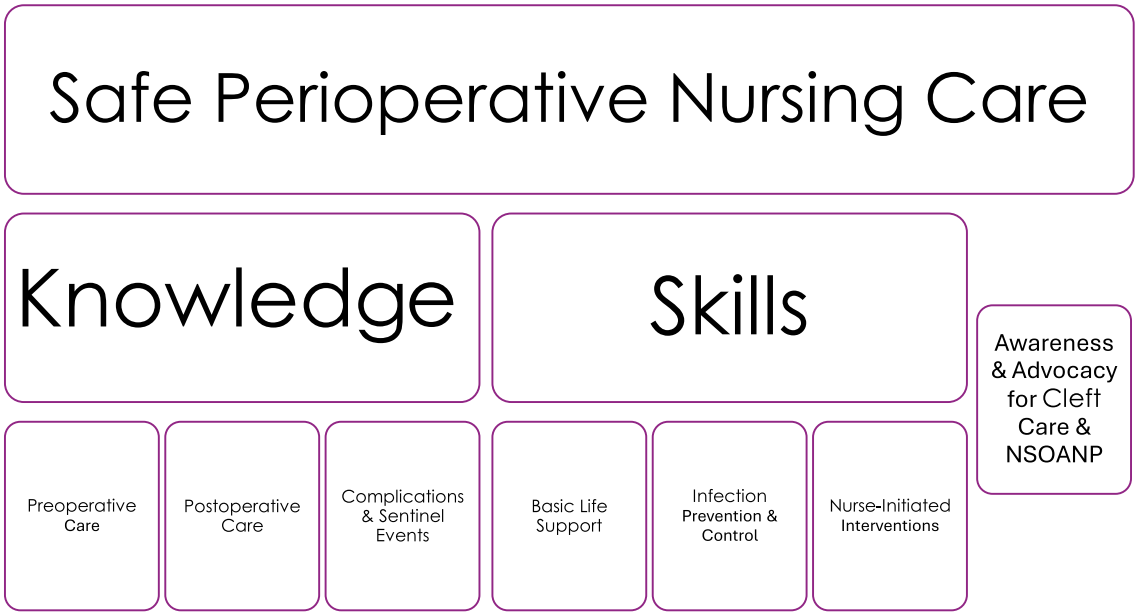

FIGURE 1
Training objectives to strengthen safe perioperative nursing care. NSOANP, National Surgical, Obstetrics, Anaesthesia and Nursing Care for Nigeria.

Data for the follow up was on step down training of others and was collected using the WhatsApp group of the participants.

Continuing professional development points were awarded by the Nursing and Midwifery Council of Nigeria (NMCN) as part of the mandatory continuing professional development programmes to enhance effective learning and a prerequisite for nursing practicing license in the country.

Data analysis

One of the 26 participants did not complete the pre- and post-training evaluations and has been excluded from analysis. Data from the training have been analysed using Excel Analyse-it$^{(R)}$ statistical software and results presented as descriptive statistics. The 5-point (very useful, useful, neutral, less useful, not useful) Likert scale was collapsed to 3-point scale (useful, neutral, not useful) to facilitate analysis. The difference between the median pre-training and post-training evaluations scores was compared using the Wilcoxon sign rank test and level of statistical significance set at $p = 0.05$.

Results

There were 15 (60%) females and 10 (40%) males from 9 public hospitals and one private hospital.

Participant performance

The pre-training evaluation score was 23–72% (median 68%) and post-training evaluation score 61–98% (median 76%), the difference between the two median scores was statistically significant ($p = 0.0001$).

Participants' feedback

Nearly all participants (96 – 100%) rated all contents of the training as useful (Figure 2). Specifically, 10 (40%) participants rated helping babies breathe as what they liked most about the training, 9 (36%) basic life support skills, 7 (28%) infection prevention and control, and 4 (16%) all contents (Table 1). Twenty-four (96%) participants indicated that there was nothing they liked least while one did not respond.

Infection prevention and control (44%), helping babies breathe (40%), and effective communication (32%) were rated as the top three most important things learnt (Table 1). Participants recommended facilitation skills (skills on how to facilitate trainings) (20%), nutrition (16%) and research skills (8%) as the top 3 aspects to be included in future trainings (Table 2).

Step down training

At 3 months of follow up, 10 (40%) of the nurses had organized step down trainings on return to their centres to share their experiences and transfer skills. Lack of funding and training materials were key challenges and barriers against step down training.

Discussion

In 2015, the world health assembly passed the landmark resolution WHA 68:15 mandating member countries to incorporate emergency and essential surgical and anaesthesia care as integral components of universal health coverage (4). Following this resolution, several countries in sub Saharan Africa, including Nigeria have launched national surgical plans to scale up access to

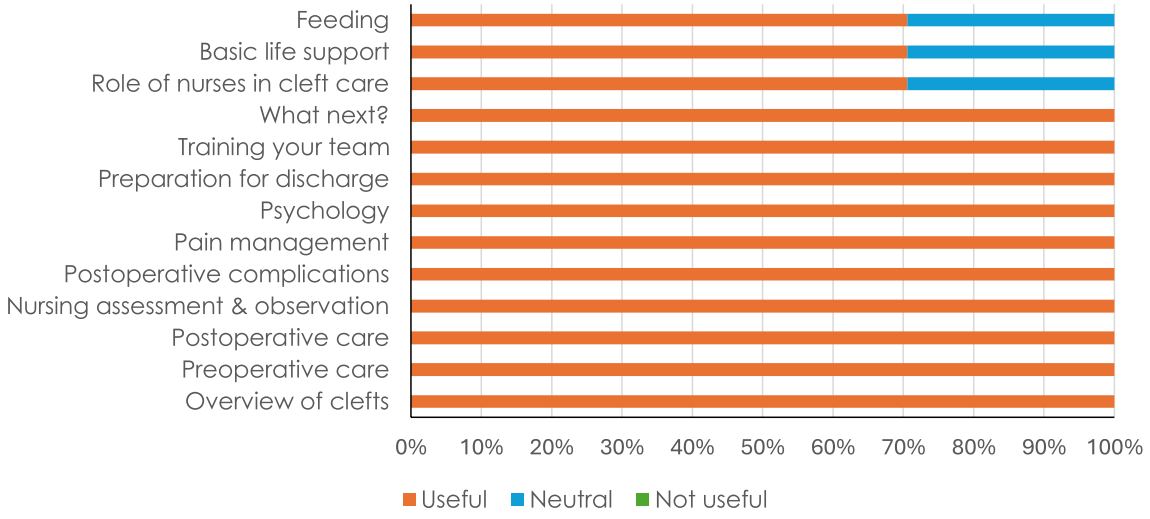

FIGURE 2
Feedback from 25 participants on usefulness of training content.

TABLE 1 Participants' feedback on most liked content and most important thing learnt.

Content	No. (%) *n* = 25
Most liked content	
Helping babies breathe	10 (40)
Basic life support	9 (36)
Infection prevention & control	7 (28)
All contents	4 (16)
Documentation	2 (8)
Nursing assessment & observation	2 (8)
Nursing management of child with cleft	2 (8)
Role of nurse in cleft care	1 (4)
Pre- & post-operative care	1 (4)
Management of emergency situation	1 (4)
Assisted breathing	1 (4)
Most important thing learnt	
Infection prevention & control	11 (44)
Helping babies breathe	10 (40)
Effective communication	8 (32)
Basic life support	5 (20)
Perioperative care of cleft patients	4 (16)
Nursing care of patients with cleft	2 (8)
Overview of clefts	1 (4)
Monitoring of vital signs	1 (4)
Taking part in step down training	1 (4)
Identification of emergencies & quick response	1 (4)
Postoperative care of cleft patients	1 (4)
Feeding	1 (4)
Nutrition	1 (4)

TABLE 2 Participant's recommendations on topics to include in future trainings.

Recommended topic	No. (%) *n* = 25
Facilitation skills	5 (20)
Nutrition	4 (16)
Research skills	2 (8)
Needed collaboration	1 (4)
Fluid management	1 (4)
Psychosocial & community engagement	1 (4)
Management of clefts with other congenital conditions	1 (4)
List of designated health facilities and their contacts	1 (4)
Management of perineum during pregnancy	1 (4)

surgical care, while others are working on such plans (5). However, expanding access to surgical care alone will not address the current high morbidity and mortality and poor surgical outcomes in the setting. Such efforts must go hand-in-hand with strengthening the delivery of safe perioperative nursing care. Moreover, nurses form the largest segment of the health workforce in most sub-Saharan Africa countries, including up to 76% in Rwanda (6). Hence, any capacity strengthening programme targeted at nurses has the potential of delivering significant impact on patient outcomes in the setting. In one report using interviews, observations, and pathway maps, and involving 2 upper-middle income, 2 lower-middle income and 1 lower income countries, barriers to safe and effective perioperative care were identified (7). Four key barriers identified in that report included limited human and structural resources, fragmental care pathways, direct and indirect cost of care for patients and patients' low expectation of care. Addressing limitations in human capacity and patients' low expectation of care can potentially be mitigated by strengthening the perioperative nursing capacity.

The study measured knowledge acquisition through pre- and post-training evaluations. While confidence in applying knowledge was not explicitly measured, participants' engagement in hands-on skill-scenarios, problem-solving exercises, and group discussions suggests enhanced procedural confidence. Behavioural change was also evaluated by independent deployment of step-down training sessions within 3 months. Although the study did not directly assess patient outcomes, participants identified infection prevention, neonatal resuscitation, and effective communication as the most impactful components of the training, all of which are critical to improving perioperative nursing care and patient safety.

The findings of this pilot implementation of the perioperative nursing training based on the Nursing Care Saves Lives programme underscore its effectiveness in enhancing perioperative nursing competence and shaping positive attitudes towards patient care.

Participants' performance, as evaluated through pre- and post-training assessments, demonstrated a significant improvement in knowledge acquisition and retention following the training. The observed increase in median evaluation scores from 68 to 76% post-training highlights the tangible impact of the training in augmenting proficiency in safe perioperative nursing care. Previous reports have emphasised the effectiveness of structured training programmes in enhancing the competencies of healthcare professionals and improving patient outcomes (8, 9). The impact of deploying evidence-based perioperative nursing training programmes has been emphasised (10). In the later report of perioperative nursing training of labour and delivery nurses, it was shown that their knowledge and competence significantly improved after completing training.

The feedback from participants in the present training programme provides some insights into the perceived utility and relevance of its contents. The overwhelmingly positive rating for all training contents is an indication of the comprehensive design of the curriculum and its alignment with perioperative learning needs. Of specific import is the high satisfaction rate with modules addressing neonatal resuscitation (helping babies breathe) and basic life support skills, underscoring the significance of these skills in perioperative nursing care. The important role of effective resuscitation and emergency care training in improving patient survival and reducing perioperative complications has been previously highlighted (10–12).

The participants were registered nurses, already practicing nursing. They were general nurses and paediatric trained nurses. As they were already trained nurses, some level of knowledge was assumed, and their background likely enhanced their knowledge retention and application.

The recommendation of participants regarding topics for inclusion in future trainings, such as skills on how to facilitate trainings, nutrition, and research, offer valuable guidance for curriculum strengthening and programmatic enhancements. Including these topics in future training iterations could further enrich the skills and learning experience for perioperative nurses.

The concept of step-down training, wherein trained nurses disseminate knowledge and skills within their healthcare facilities, holds immense potential for cascading the benefits of the training programme to more nurses and staff. However, limited funding and lack of training materials remain important barriers that require institutional support and resources. In addition, collaboration between these institutions and donors are crucial to the sustainability and scalability of this safe perioperative nursing training across Nigeria.

Conclusion

The Nursing Care Saves Lives (NCSL) programme employed several approach to assess and track behaviour change among the nurses. Beyond evaluating knowledge acquisition, the programme focused on measuring the application of skills in real-world clinical settings. Structured pre- and post-training evaluations demonstrated significant improvements in clinical decision-making and procedural confidence, indicating both knowledge gain and the ability to translate learning into practice. Simulated scenarios and direct observation during training provided real-time feedback, ensuring skill mastery before participants returned to their clinical roles. Behaviour change was further assessed by monitoring knowledge dissemination, with follow-up showing that 40% of participants had independently conducted step-down training sessions for colleagues within 3 months, reflecting internalisation of key concepts and sustained confidence in their application. In addition, 96–100% of participants rated key components of the training as useful, with infection prevention, neonatal resuscitation, and effective communication identified as the most impactful areas of practice change. The combination of objective skill assessments and subjective self-reports reinforces the programme's effectiveness in enhancing behavioural change.

The outcome of this pilot implementation has shown that the NCSL training programmes adapted for safe perioperative nursing care in general, has the transformative potential of promoting and strengthening safe perioperative nursing care. The training is desirable in the drive to expand access to timely and safe surgical care in the setting and would enhance patients' safety and improvements in surgical outcomes. Efforts need to be directed towards refining and scaling up the programme across Nigeria.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was obtained from the institutional review board (health research and ethics committee) of National Hospital, Abuja, Nigeria, as part of Nigeria's NSOANP creation and implementation process. In addition, participants were informed that participation in the training was voluntary and accepting to participate implied consent to participate, but no written consent was obtained.

Author contributions

OAL: Conceptualization, Data curation, Project administration, Writing – original draft, Writing – review & editing. NOp: Data curation, Project administration, Writing – original draft, Writing – review &

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

1. Azad A, Min J-G, Syed S. Sara Anderson - continued nursing education in low-income and middle-income countries: a narrative synthesis: BMJ. *Glob Health*. (2020) 5:e001981. doi: 10.1136/bmjgh-2019-001981

2. Training manual. Nursing care saves lives. New York: Smile Train (2024).

3. National surgical, obstetric, anaesthesia and nursing plan. (2019). Federal Ministry of Health, Abuja. Available online at: (https://www.pgssc.org/nationalsurgical-planning).

4. World health Assembly. (2015). Strenghtening emergency and essential surgical care and anaesthesia as a component of universal health coverage. Available online at: (https://apps.who.int/gb/ebwha/pdf_files/WHA68/A68_R15-en.pdf).

5. Bekele A, Alayande BT, Powell BL, Obi N, Seyi-Olajide JO, Riviello RR, et al. National surgical healthcare policy development and implementation: where do we stand in Africa? *World J Surg*. (2023) 47:3020–9. doi: 10.1007/s00268-023-07131-0

6. Mukantwari J, Omondi L, Ryamukuru D. Perioperative nursing training in Rwanda in partnership with American universities: the journey so far. *Rwanda J Med Health Sci*. (2021) 4:185–96. doi: 10.4314/rjmhs.v4i1.13

7. Bedwell GJ, Dias P, Hahnle L, Anaeli A, Baker T, Beane A, et al. Barriers to quality perioperative care delivery in low- and middle-income countries: a qualitative rapid appraisal study. *Anesth Analg*. (2022) 135:1217–32. doi: 10.1213/ANE.0000000000006113

8. Smith AF, Youngson GG, Jolly BC, Green L. Audit of resuscitation skills and knowledge among healthcare providers in a private hospital in Malaysia. *Br J Anaesth*. (2019) 123:e108–11.

9. Thomas L, Gallauresi B, Mehta R. Implementation of an evidence-based pediatric sepsis protocol in a community hospital improves delivery of care. *Pediatr Crit Care Med*. (2020) 21:e172–80.

10. Stucky CH, Knight AR, Dindinger RA, Maio S, House S, Wymer JA, et al. Periop101: improving perioperative nursing knowledge and competence in labour and delivery nurses through an evidence-based education and training program. *Mil Med*. (2023) 189:24–30.

11. Berglund E, Jonsson K, Maurex L, Anderzén-Carlsson A. Simulation-based team training in a Swedish neonatal intensive care unit: a multidisciplinary approach. *BMJ Simul Technol Enhanc Learn*. (2018) 4:226–33.

12. Soar J, Monsieurs KG, Ballance JHW, Barelli A, Biarent D, Greif R, et al. European resuscitation council guidelines for resuscitation 2015: section 9. Principles of education in resuscitation. *Resuscitation*. (2015) 95:288–301.

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Development, implementation, and evaluation of a rapid response system at a Nigerian teaching hospital, a novel idea in sub-Saharan Africa

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Aim: Little is known about the incidence of clinical deterioration and cardiopulmonary arrest (CPA) on general hospital units in low-and middle-income countries (LMICs) or how rapid response systems (RRSs) might impact these events. Implementation of RRSs in high-income countries has been shown to reduce the incidence of CPA and mortality. The aim of this study was to determine whether implementation of an RRS is feasible in an LMIC medical center.

Methods: We developed and implemented an RRS in a large academic medical center in Lagos, Nigeria, in three phases: (1) Needs assessment and stakeholder engagement, (2) Infrastructure setup and education, and (3) Implementation and data collection. We collected data on incidence of rapid response events, attendance ratio and time of arrival of the designated clinical staff, triggers for the rapid response calls and common interventions at the events.

Results: Over the 7 months study period, 997 patients were admitted to the intervention-eligible units, and 95 RRS events occurred in 55 patients. In 11 RRS activations (11.6%), no rapid response team member responded. Anesthesia residents attended 73.7% of the events, and anesthesia techs and nurses attended roughly 38% each. Internal medicine residents responded to 13.7% of RRS activations. The average time to arrival was 13 min. The most common trigger was altered mental status, followed by hypoxia and hypotension. Seventy-six percent of patients survived their initial RRS activation, and 83% died while in hospital. Common interventions were vasopressor use, oxygen supplementation, and intravenous fluid administration. No patient was transferred to the designated intensive care unit after an RRS activation owing to lack of beds. Six patients were transferred to the makeshift ICU, all of which required vasopressor support.

Conclusion: While barriers remain, the development and implementation of an RRS program in an LMIC medical center is feasible.

KEYWORDS

pilot, hospital-based, multidisciplinary, rapid response system, failure to rescue

1 Introduction

Clinical deterioration resulting in cardiopulmonary arrest (CPA) among hospitalized patients on general hospital units (also known as failure to rescue) is associated with very high mortality and has best been described in high-income countries (1–4). An extensive body of literature demonstrates that in high-income countries, clear warning signs often precede deterioration to CPA, leaving substantial time to intervene (5, 6). Data for low- and middle-income countries (LMICs) are scarce but suggest an unacceptably high incidence of CPAs, many of which are not witnessed (7). Given that LMICs account for nearly 90% of all world-wide trauma-related deaths, maternal deaths, and deaths from overwhelming infections (5, 8, 9), we suspect that unrecognized clinical deterioration on general units in these countries contributes substantially to these high rates of adverse outcomes.

Rapid response systems (RRSs) were developed in high-income countries as a patient- safety intervention to address this dangerous problem (9, 10). At its core, an RRS includes an afferent component that establishes processes and criteria for identifying patients who are deteriorating or at risk of deteriorating and activating a response team of clinicians that forms the efferent component. Fully mature RRSs also include administrative components, education components, and components for collecting and analyzing data that are used for ongoing quality improvement and regulatory requirements.

The rapid response team is typically activated by single physiologic or laboratory data thresholds or amalgamated and weighted scores based on these data, as well as team or family member concern. The responding team is a multidisciplinary group of clinicians that may include physicians, nurses, anesthesia techs, pharmacists, and others, depending on local resources and staffing availability. This team may also proactively evaluate high-risk general unit patients (known as critical care outreach) and educate and act as a liaison to unit staff. Various RRS models have been implemented in many developed countries over the last 20–25 years as a potent patient-safety intervention. In the United States, they were endorsed by the Institute for Healthcare Improvement's "100,000 Lives Campaign" in 2005 and then required by the American Joint Commission for Hospital Accreditation as part of the Commission's Patient Safety Goal for 2009. Such programs have reduced unanticipated CPA and in-hospital mortality in developed countries for both adult and pediatric patients (9, 10).

Patient safety and mitigating preventable harm have become a global health priority; however, RRSs have not been fully evaluated in low-resource settings where the need is arguably the greatest. One study from an LMIC in South Asia demonstrated RRS effectiveness in reducing CPA and mortality (11). Such programs could have tremendous impact in sub- Saharan Africa. Because the hospitalized patients there are typically younger, often with relatively few comorbidities, well-orchestrated and timely response to acute deterioration could potentially prevent complete decline and CPA (12). Such programs may also serve as an indicator for the readiness of local healthcare systems in providing effective emergency, essential surgical, and anesthesia care as components of universal health coverage, as urged by the 68th Assembly of the World Health Organization (13).

Additionally, the implementation of RRSs may be especially beneficial in sub-Saharan Africa, where critical care facilities are scarce despite the greater burden of critical illness (14). For example, Uganda has one intensive care unit (ICU) bed per million population (8). Nigeria only has 380 critical care nurses for a population of 140 million, compared with more than 500,000 critical care nurses in the United States for a population of 324 million (15, 16). Therefore, complex patients are cared for on the general hospital unit, adding strain to overworked and under-resourced nurses. As a result, inadequate patient assessment and monitoring, inappropriate treatment, and communication breakdown contribute to poor outcomes in LMICs (17). Moreover, the implementation of RRSs could improve patient-safety culture through improved critical care training, care coordination, and earlier identification of deterioration trends that illuminate faulty processes.

In this report, we describe development and implementation of an RRS at Lagos University Teaching Hospital (LUTH), the effects of the RRS on the quality of critical care on general units and lessons learned about RRS implementation in similar contexts.

2 Materials and methods

2.1 Setting

Lagos University Teaching Hospital is a large tertiary teaching hospital in Nigeria. It is a government hospital with 761 beds and a six-bed ICU. The ICU is managed by anesthesiologists and patients on the floor units are managed by internal medicine doctors and surgeons. Nigeria is an LMIC in West Africa, with a total population of ~ 182 million. The mortality rate of Nigerians adult males is 356 per 1,000 male adults https://data.worldbank.org/indicator/SP.DYN.AMRT.MA?locations . We established an academic partnership and collaboration between LUTH team members in Lagos, Nigeria, and the Johns Hopkins University School of Medicine in Baltimore, MD, United States, to develop and implement an RRS at LUTH. The project occurred in three phases: (1) Needs assessment and stakeholder engagement, (2)

Infrastructure setup and education, and (3) Implementation rollout and data collection. We prospectively collected data on patient demographics and clinical outcome during the implementation. We had IRB approval from both Johns Hopkins University and LUTH.

2.2 Phase 1: needs assessment and stakeholder engagement

Investigators from Johns Hopkins traveled to Nigeria for an introductory meeting with hospital administrators and department heads. Participants included leadership in the departments of nursing, anesthesiology, surgery, internal medicine, and pharmacy, as well as the chief residents in these specialties. We jointly reviewed their existing practice of identifying and triaging high-acuity patients and the potential failure modes and deficiencies in their practice and processes. We subsequently discussed the proposed project and its potential usefulness in improving the delivery of quality care to the patients at LUTH. We jointly identified potential hurdles to successful implementation, including perceptions of increased work burden, lack of standardized triggers for rapid response calls, poor organization of command chains, poor communication infrastructure, poor access to emergency medications and clinical monitors, and limitations in the number of ICU beds. We worked with staff and local vendors to address some of the potential obstacles.

2.3 Phase 2: infrastructure setup and education

2.3.1 Communication tools

We worked with a local telecommunications company to create stationary phones on the study units that were designed to call mobile "rapid response phones" with the push of one number. This call was intended to activate the mobile phones that would be carried by members of the rapid response teams.

2.3.2 Crash carts and monitors

We worked with the nursing team and pharmacists to update the crash carts with essential supplies and medications, including advanced cardiac life support medications. Importantly, patients were to be charged for the medications after administration in an emergency setting, as opposed to the existing practice of having family members purchase the medications from the pharmacy before use, a very time-inefficient and costly practice.

2.3.3 Assessment tools

The research team and the providers at LUTH endorsed the use of the Modified Early Warning Score (MEWS) protocol as an identification tool (18, 19). MEWS is a vital sign–driven protocol that amalgamates data into a weighted score for predicting deterioration risk and is used by bedside nurses to identify at-risk patients (Figure 1) (20).

Nurses were then empowered to activate the RRS team with the established protocol.

2.3.4 Rapid response team (RRS efferent component)

Rapid response teams consisted of two providers (an anesthesia resident and an internal medicine resident), a senior ICU nurse with the expertise and clinical flexibility to attend remote events and an anesthesia technician. The anesthesia technician functioned both in and out of the operating room as airway support personnel, facilitating access to airway equipment, and providing technical assistance for airway support among their other duties. Rapid response team members had a weekly schedule, and each carried a dedicated RRS mobile phone while on call.

2.3.5 The study units

Two intervention units were identified based on perceived readiness for culture change (one medical unit and one surgical unit). The study team spent time in these units to observe current practices, engage the local staff, and identify a local champion. In each intervention unit, a crash cart was positioned close to the nursing station, along with a makeshift, temporary ICU bed that could be used until a dedicated ICU bed became available or until the patient improved sufficiently to return to their regular unit bed. The decision to use the makeshift ICU bed would be at the discretion of the rapid response teams. Colorful paper copies of the MEWS tool sheet were available on the units and attached to each patient's chart for easy access (Figure 1). Two control units were identified for comparison purposes.

2.3.6 Campus-wide education and introduction of the project

We embarked on intensive training both for the frontline providers who were involved in the identification of at-risk patients and for responding providers. Designated members of the research team participated in a campus-wide multidisciplinary grand rounds with over 100 attendees. We delivered more focused training to the providers and nursing staff who would eventually constitute the rapid response teams.

The bedside nurses (afferent limb) received an online training course on the MEWS tool that would be used to identify at-risk patients. The house staff on the response teams (efferent limb) were trained in the Fundamentals of Critical Care Support, a course designed by the Society of Critical Care Medicine to train non-intensivists to identify and manage critically ill patients pending appropriate critical care consultation[1]. The nursing staff and anesthesia technicians who were part of the efferent limb of the RRS were also engaged in intensive nursing critical care courses before implementation.

2.4 Phase 3: implementation and data collection

We implemented the RRS in January 2019 and collected data through July 2019. We collected data on patients admitted to the intervention units and control units by using prospective

1 https://www.sccm.org/Education-Center/Educational-Programming/Fundamentals/Fundamental-Critical-Care-Support

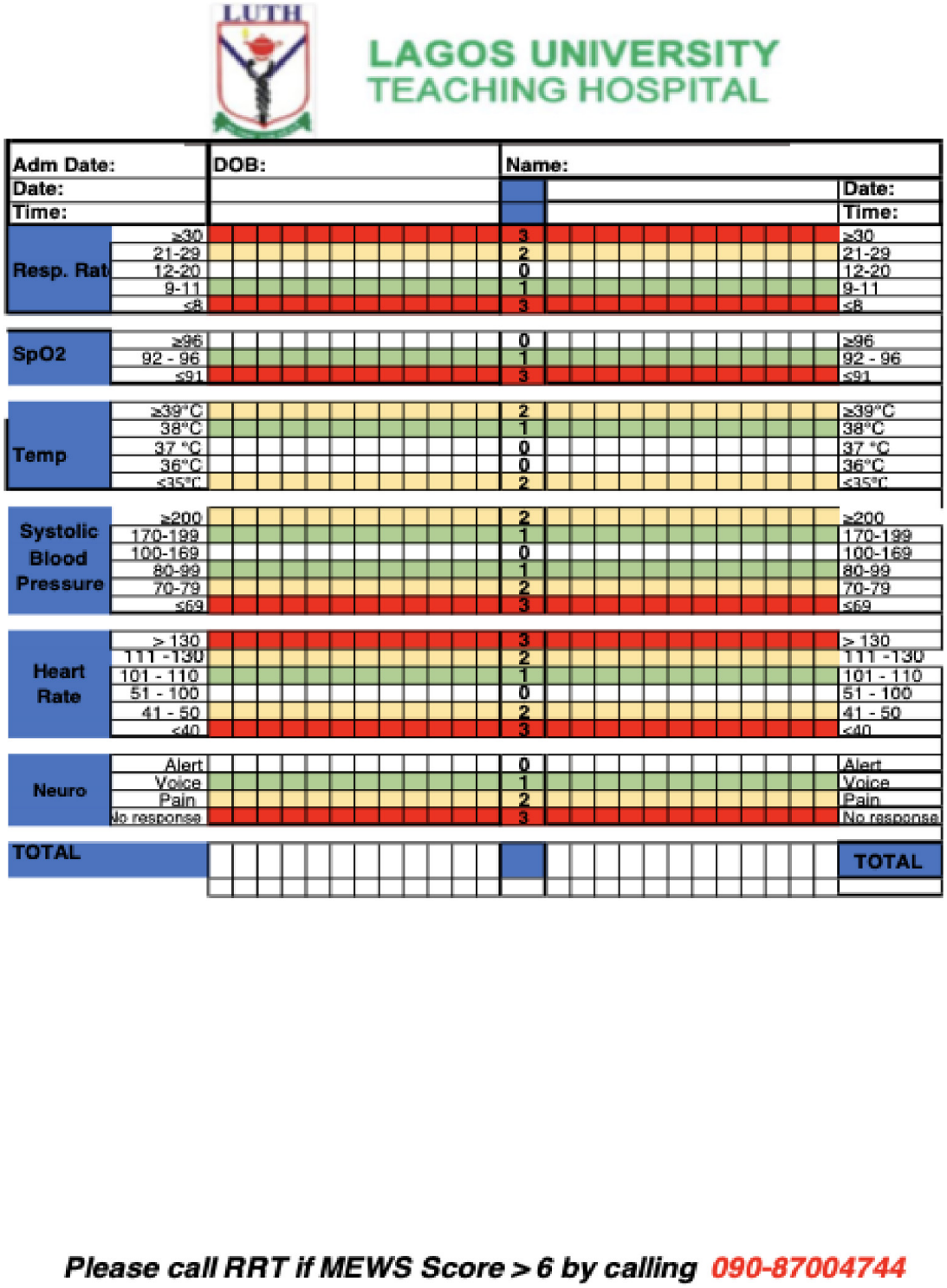

FIGURE 1
Modified Early Warning Scores (MEWS) used to determine when the rapid response system should be activated (21).

chart reviews that included data on patient demographics, admission diagnosis, comorbid conditions, hospital length of stay, and mortality.

On a bimonthly basis, we provided motivational lunches and talks by inspirational guest speakers. We gave awards to the most "responsive resident" and "best RRS nurse," and monthly "Nurse Angel" awards. In addition, rapid response team T-shirts were used to motivate and encourage the residents and nurses.

All RRS calls were reviewed during a monthly meeting of stakeholders from the various departments. Data obtained from the data collection tool were collated, and successes and barriers were discussed and recorded. Improvement plans were put in place

regularly. We defined feasibility as having at least two members of the efferent team respond to RRS event more than 50% of the time.

3 Results

The RRS was implemented over a 7 months period during which 577 patients were admitted to the intervention units and 420 to the control units (Table 1). A total of 95 events in the intervention units prompted activation of the RRS team. Eighty-four (88%) of these activations resulted in at least one team member response to the activation. In 11 RRS activations (11.6%), no rapid response team member responded. None of the RRS events had all four team members present (Figure 2A). Anesthesia residents were the most frequent responders, arriving at 70 events (73.7%), followed by anesthesia techs and nurses with ~38% attendance each (Figure 2B). The average time to arrival of any rapid response team member was 13 min. The clinicians that missed the rapid response reported being occupied with other clinical responsibilities at the time of the events.

The most common trigger for an RRS activation was altered mental status, followed by hypoxia and hypotension (Figure 2C). The 95 RRS activations involved 55 unique patients. Six patients

TABLE 1 Baseline characteristics for patients admitted to intervention units from January 2019 through July 2019.

Characteristics	Categories	Survival group (n = 474)	Mortality group (n = 103)	P-value
Age, years, median (IQR)	–	45 (34–60)	56 (44–49)	0.001
Age, n (%)	18–44	209 (44.1)	28 (27.2)	0.002
	45–64	166 (35.0)	40 (38.8)	
	> 64	99 (20.9)	35 (34.0)	
Sex, n (%)	Male	246 (51.9)	56 (54.4)	0.759
	Female	228 (48.1)	47 (45.6)	
Diagnosis, n (%)	Infection	88 (18.6)	20 (19.4)	0.000 ($p < 0.001$)
	Neoplasm	60 (12.7)	33 (32.0)	
	Neurologic	54 (11.4)	5 (4.9)	
	Cardiac	64 (13.5)	16 (15.5)	
	Other	208 (43.8)	29 (28.2)	
Pre-existing conditions, n (%)	DM	81 (17.1)	14 (13.6)	0.559
	CKD	35 (7.4)	8 (7.8)	1.000
	HIV/AIDS	24 (5.1)	9 (8.7)	0.091
	HTN	183 (38.6)	37 (35.9)	0.692
LOS, days, median (IQR)	–	9 (5–15)	10 (4.5–19)	0.002
Characteristics	**Categories**	**Survival group (n = 351)**	**Mortality group (n = 69)**	**P-value**
Age, years, median (IQR)	–	46 (37–60)	44 (37–65)	0.421
Age, n (%)	18–44	152 (43.3)	35 (50.7)	0.033
	45–64	137 (39.0)	16 (23.2)	
	> 64	62 (17.7)	18 (26.1)	
Sex, n (%)	Male	164 (46.7)	32 (46.4)	1.000
	Female	187 (53.3)	37 (53.6)	
Diagnosis, n (%)	Infection	74 (21.1)	18 (26.1)	0.085
	Neoplasm	57 (16.2)	17 (24.6)	
	Neurologic	79 (22.5)	7 (10.1)	
	Cardiac	20 (5.7)	2 (2.9)	
	Other	121 (34.4)	25 (36.2)	
Pre-existing conditions, n (%)	DM	72 (20.5)	8 (11.6)	0.194
	CKD	22 (6.3)	4 (5.8)	0.735
	HIV/AIDS	26 (7.4)	10 (14.5)	0.092
	HTN	140 (39.9)	20 (29.0)	0.117
LOS, days, median (IQR)	–	10 (6–17)	11 (4–27)	0.001

AIDS, acquired immunodeficiency syndrome; CKD, chronic kidney disease; DM, diabetes mellitus; HIV, human immunodeficiency virus; HTN, hypertension; IQR, interquartile range; LOS, length of stay.

had two RRS activations and 17 had three RRS activations during their hospital course. Figure 2D shows the percent distribution of the 95 RRS activations stratified by RRS event number for each patient and outcome (dead or alive) of the rapid response intervention.

Of the 55 first-time RRS activations, 42 (76%) patients survived the event. However, 35 (83%) patients who survived ultimately died during their hospital course. Interventions commonly included the addition or optimization of vasopressors (42%), intravenous fluid administration (42%) and oxygen supplementation (21%), (Table 2). None of the RRS activations resulted in a transfer to the designated ICU because no beds were available. Six patients were managed in the temporary ICU beds set up on the intervention units, as described in the Methods. This decision was made at the discretion of the rapid response team and based on availability of the continuous monitor. The family refused advanced ICU care on two occasions owing to financial constraints.

Mortality rate was slightly lower in the control units during the investigation period, although our study was not adequately powered to determine a difference (Table 3).

4 Discussion

We successfully implemented an RRS at a resource-limited LMIC hospital (LUTH) through multidisciplinary engagement and staff organization, intense education, and initiation of improved communication structures, protocols, and critical care tools. To our knowledge, little has been published on such implementation in a resource-limited environment (20, 22). This program was overall well received and perceived to be of great benefit to the staff and patients at LUTH. Using a train-the-trainers model, this program is potentially scalable to units such as maternal medicine, the emergency department, and perhaps other teaching hospitals in the country (23, 24).

Many obstacles and limitations were encountered during this project that should be considered before expansion to other areas of the hospital or other institutions in resource-limited LMIC facilities. One of the primary and initial obstacles encountered was a delay in establishing a telephone system to standardize activation of the rapid response team members, which in turn delayed implementation of the rapid response program. Such a was a novel concept in Nigerian public

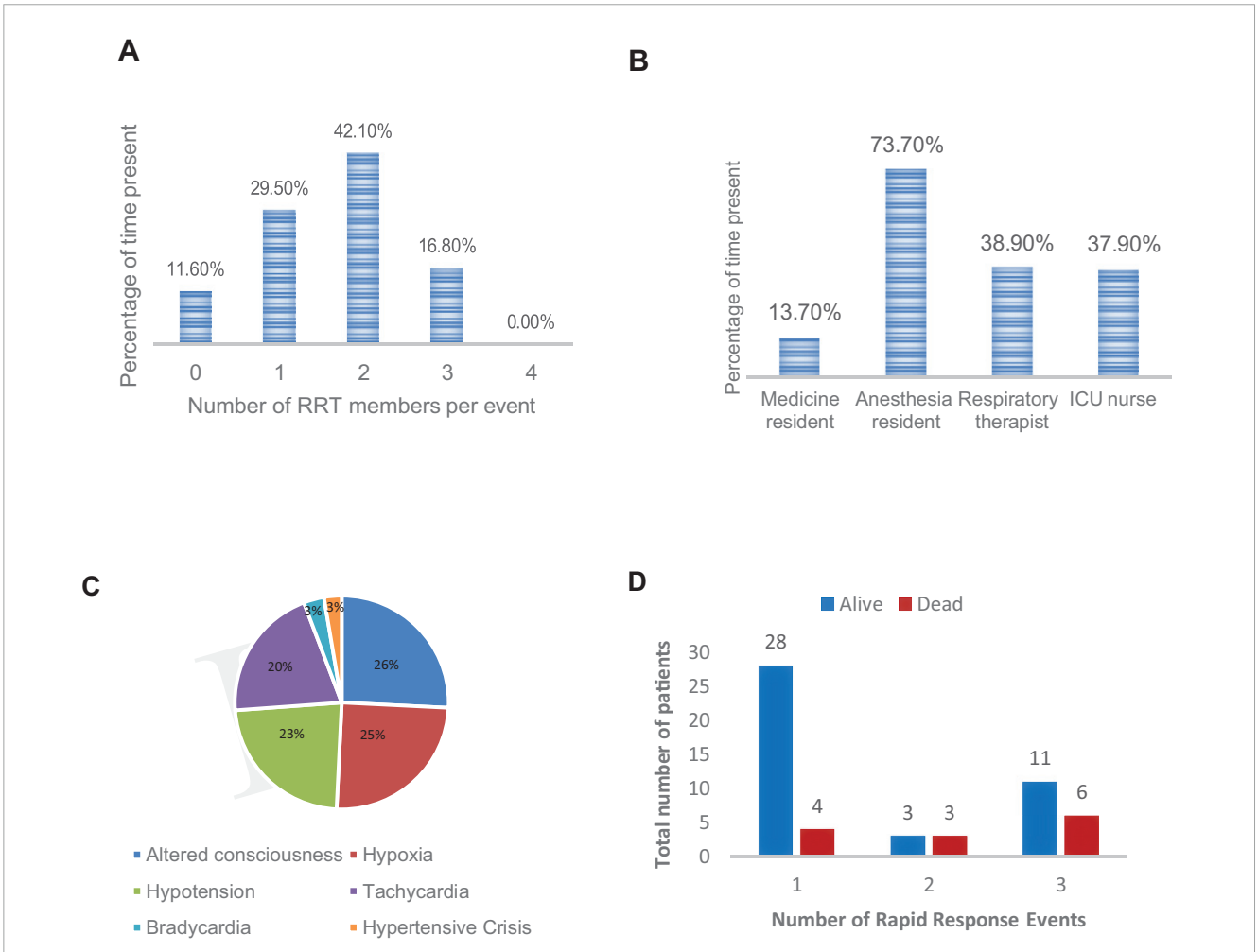

FIGURE 2
Characteristics of rapid response team activations. **(A)** Number of rapid response team members per event. **(B)** Rapid response attendance by role. **(C)** Indications for rapid response team activation. **(D)** Rapid response team event number stratified by outcome. ICU, intensive care unit; RRT, rapid response team.

TABLE 2 Frequency of interventions during rapid response team activation.

Intervention	Frequency (% of rapid response events)
Oxygen support	20 (21%)
Intravenous fluid	40 (42%)
Vasopressor support	40 (42%)
Antibiotics	1 (< 1%)
Intubation	3 (< 1%)
ICU transfer.	0 (0%)
Blood transfusion	1 (< 1%)
Makeshift ICU with continuous monitoring	6 (< 1%)

ICU, intensive care unit.

TABLE 3 Admissions and mortality rates in control and intervention units from January 2019 Through July 2019.

Interventions units	Survival group	Mortality group (%)	*P*-value
Interventions units			
E5	228	56	0.729
A3	246	47	
Total	474	103 (21.7)	–
Control units			
A2	164	32	1.000
A4	187	37	
Total	351	69 (19.7)	–
Combined Total	997	172	–

hospitals, where everyone who has a personal mobile phone uses it in a decentralized manner for communication. However, that system was inadequate for implementing an RRS and required multiple consultations with different telecommunications companies to create a model that would work at the hospital. Centralized communication systems are ubiquitous in high-income countries, but establishing an effective, affordable, standardized method of activating the RRS team members can be quite difficult in LMICs.

A second obstacle was the perceived additional workload among both the nursing and house staff. Nurses are often overextended, especially during night shifts, because of the high number of high-acuity patients and high patient-to-nurse ratios, sometimes as high as one nurse to eight patients. During preparation for implementation, the nursing staff expressed concern over the perceived additional burden (especially documentation burden) on the already overtasked workforce. We addressed this concern by simplifying the documentation to one page. Although this change truncated the amount of data collected by event, it was a compromise that was necessary to promote documentation compliance.

A more challenging obstacle and limitation to address was the resistance from the medicine house staff to participate in what they perceived as a research project that was of minimal benefit to them. We addressed this concern in several meetings where the house staff were encouraged to view the quality improvement project as an opportunity for improving the care that they provided to patients who were already on their service, as well as the potential to improve outcomes and their hospital policy. Despite these efforts, internal medicine resident attendance at RRS activations remained substantially lower than that of the other team members. Improved strategies for motivation and engagement are necessary.

Other limitations and obstacles inherent to the healthcare systems in LMIC environments that we encountered included the common practice of requiring family members to purchase medications from the pharmacy before administration. Such systems do not exist in the hospitals and countries that have contributed nearly all of the data in support of RRS effectiveness. The delays from this type of pharmaceutical economic system severely impede the administration of potentially life-saving therapies during critical patient deteriorations and emergencies. Charging patients/families after the administration of indicated medications was a major culture change for LUTH and not without its associated financial risks should the patient and family be unable to pay. These financial hardships were also noted in the fact that in two of the RRS activations, the family refused escalation of care to the ICU because of costs. Cost considerations by the hospital and health system, as well as by the patients and their families, will remain a challenging barrier to success.

Notably, none of the patients who had an RRS activation were transferred to the ICU, though several met criteria. The literature reports different rates for ICU admission after an RRS activation (25), but most patients remain on the general unit after assessment and treatment by the rapid response team. We are unable to compare our findings with those of that body of literature, which is generated almost exclusively in countries and environments where ICU access is not limited or only minimally limited. LUTH, a 761-bed tertiary academic medical center, has only six ICU beds. In contrast, Johns Hopkins Hospital, a 960-bed institution, has 128 adult ICU beds, a ratio more typical of high-income countries. The severe limitation on ICU bed access in LMICs has implications for the implementation of RRS in those environments. There were 40 rapid response events that prompted the use of vasopressors, six of which utilized the temporary ICU-capable beds. This mobile ICU is a potential strategy for stabilizing patients and keeping them on the general unit.

This program helped highlight some of the deficiencies in the existing system, such as inadequate staffing and organization, inconsistent access to emergency supplies, and inadequacies of existing communication tools. Another important issue that was revealed was the weak infrastructure for identification and triage of terminally ill patients, resulting in minimal palliative care services and overuse of already scarce resources such as ventilators.

A final limitation is that this was a single-center study. However, we believe that LUTH is prototypical of most academic centers in Nigeria and perhaps in other LMICs and therefore a good

model for what can be replicated at many institutions throughout Nigeria and sub-Saharan Africa.

5 Conclusion

Our study supports the hypothesis that the development and implementation of an RRS in an LMIC hospital is feasible. However, there is a need for more trained personnel and better infrastructure and standardized protocols for larger scale dissemination. Barriers such as physician engagement remain an impediment to full utilization. The documentation of RRS events and focused multidisciplinary review of each event can improve the quality of this intervention. Hospital buy-in and investment in staff and infrastructure can expand the impact of such programs throughout regional and national hospitals.

Data availability statement

The original contributions presented in this study are included in this article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Johns Hopkins University IRB, Lagos University teaching Hospital IRB. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

PA: Conceptualization, Investigation, Writing – original draft, Writing – review and editing. SL: Data curation, Investigation, Software, Writing – original draft. AL: Conceptualization, Investigation, Writing – review and editing. CE: Conceptualization, Investigation, Writing – review and editing. VP: Conceptualization, Investigation, Writing – review and editing. OB: Conceptualization, Investigation, Writing – review and editing. ID: Investigation, Writing – review and editing. JS: Conceptualization, Investigation, Methodology, Writing – review and editing. BW: Conceptualization, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Charlson M, Sax F, MacKenzie C, Braham R, Fields S, Douglas R. Morbidity during hospitalization: Can we predict it? *J Chronic Dis.* (1987) 40:705–12. doi: 10.1016/0021-9681(87)90107-x

2. Schein R, Hazday N, Pena M, Ruben B, Sprung C. Clinical antecedents to in-hospital cardiopulmonary arrest. *Chest.* (1990) 98:1388–92. doi: 10.1378/chest.98.6.1388

3. Smith A, Wood J. Can some in-hospital cardio-respiratory arrests be prevented? A prospective survey. *Resuscitation.* (1998) 37:133–7. doi: 10.1016/s0300-9572(98)00056-2

4. Franklin, C, Mathew J. Developing strategies to prevent inhospital cardiac arrest: Analyzing responses of physicians and nurses in the hours before the event. *Crit Care Med.* (1994) 22:244–7. doi: 10.1001/jama.1991.03460210061030

5. Buist M, Jarmolowski E, Burton P, Bernard S, Waxman B, Anderson J. Recognising clinical instability in hospital patients before cardiac arrest or unplanned admission to intensive care. A pilot study in a tertiary-care hospital. *Med J Aust.* (1999) 171:22–5. doi: 10.5694/j.1326-5377.1999.tb123492.x

6. Bedell S, Deitz D, Leeman D, Delbanco T. Incidence and characteristics of preventable iatrogenic cardiac arrests. *JAMA.* (1991) 265:2815–20. doi: 10.1097/00003246-199402000-00003

7. Bellomo R, Goldsmith D, Uchino S, Buckmaster J, Hart G, Opdam H, et al. Prospective controlled trial of effect of medical emergency team on postoperative morbidity and mortality rates. *Crit Care Med.* (2004) 32:916–21. doi: 10.1097/01.ccm.0000119428.02968.9e

8. Mock C, Joshipura M, Goosen J, Lormand J, Maier R. Strengthening trauma systems globally: The essential trauma care project. *J Trauma.* (2005) 59:1243–6. doi: 10.1097/01.ta.0000197290.02807.de

9. Winters B, Weaver S, Pfoh E, Yang T, Pham J, Dy S. Rapid-response systems as a patient safety strategy: A systematic review. *Ann Intern Med.* (2013) 158:417–25. doi: 10.7326/0003-4819-158-5-201303051-00009

10. Maharaj R, Raffaele I, Wendon J. Rapid response systems: A systematic review and meta-analysis. *Crit Care.* (2015) 19:254. doi: 10.1186/s13054-015-0973-y

11. Dünser M, Baelani I, Ganbold L. A review and analysis of intensive care medicine in the least developed countries. *Crit Care Med.* (2006) 34:1234–42. doi: 10.1097/01.CCM.0000208360.70835.87

12. Jochberger S, Ismailova F, Lederer W, Mayr V, Luckner G, Wenzel V, et al. Anesthesia and its allied disciplines in the developing world: A nationwide survey of the Republic of Zambia. *Anesth Analg.* (2008) 106:942–8. doi: 10.1213/ane.0b013e318166ecb8

13. Price R, Makasa E, Hollands M. World Health Assembly Resolution WHA68.15: Strengthening Emergency and Essential Surgical Care and Anesthesia as a component of universal health coverage—addressing the public health gaps arising from lack of safe, affordable and accessible surgical and anesthetic services. *World J Surg.* (2015) 39:2115–25. doi: 10.1007/s00268-015-3153-y

14. Firth P, Ttendo S. Intensive care in low-income countries–A critical need. *N Engl J Med.* (2012) 367:1974–6. doi: 10.1056/NEJMp1204957

15. Requejo J, Merialdi M, Bustreo F. Improving global maternal health: Progress, challenges, and promise. *Curr Opin Obstet Gynecol.* (2011) 23:465–70. doi: 10.1097/GCO.0b013e32834cdc9b

16. Cheng A, West T, Limmathurotsakul D, Peacock S. Strategies to reduce mortality from bacterial sepsis in adults in developing countries. *PLoS Med.* (2008) 5:e175. doi: 10.1371/journal.pmed.0050175

17. Murthy S, Adhikari N. Global health care of the critically ill in low-resource settings. *Ann Am Thorac Soc.* (2013) 10:509–13. doi: 10.1513/AnnalsATS.201307-246OT

18. Gardner-Thorpe J, Love N, Wrightson J, Walsh S, Keeling N. The value of Modified Early Warning Score (MEWS) in surgical in-patients: A prospective observational study. *Ann R Coll Surg Engl.* (2006) 88:571–5. doi: 10.1308/003588406X130615

19. Kruisselbrink R, Kwizera A, Crowther M, Fox-Robichaud A, O'Shea T, Nakibuuka J, et al. Modified Early Warning Score (MEWS) Identifies critical illness among ward patients in a resource restricted setting in Kampala, Uganda: A prospective observational study. *PLoS One.* (2016) 11:e0151408. doi: 10.1371/journal.pone.0151408

20. Rashid M, Imran M, Javeri Y, Rajani M, Samad S, Singh O. Evaluation of rapid response team implementation in medical emergencies: A gallant evidence based medicine initiative in developing countries for serious adverse events. *Int J Crit Illn Inj Sci.* (2014) 4:3–9. doi: 10.4103/2229-5151.128005

21. DeVita MA. *Textbook of rapid response systems: Concept and implementation*, 3rd Edn. Cham: Springer (2024). doi: 10.1007/978-3-031-67951-3

22. Anwar-ul-Haque N, Saleem AF, Zaidi S, Haider SR. Experience of pediatric rapid response team in a tertiary care hospital in Pakistan. *Indian J Pediatr.* (2010) 77:273–6. doi: 10.1007/s12098-010-0032-2

23. Nexø M, Kingod N, Eshøj S, Kjærulff E, Nørgaard O, Andersen T. The impact of train-the-trainer programs on the continued professional development of nurses: A systematic review. *BMC Med Educ.* (2024) 24:30. doi: 10.1186/s12909-023-04998-4

24. Anderson C, Taira B. The train the trainer model for the propagation of *resuscitation* knowledge in limited resource settings: A systematic review. *Resuscitation.* (2018) 127:1–7. doi: 10.1016/j.resuscitation.2018.03.009

25. Kurita T, Nakada T, Kawaguchi R, Fujitani S, Atagi K, Naito T, et al. Impact of increased calls to rapid response systems on unplanned ICU admission. *Am J Emerg Med.* (2020) 38:1327–31. doi: 10.1016/j.ajem.2019.10.028

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