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Original Research Paper

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The use of Mobile Surgical Units in austere environments and rural areas: a systematic review.

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Abstract

Background: Mobile surgical units (MSU) have been used since World War II to facilitate surgical care at the frontlines. However, their role in modern-day surgical practice, particularly in austere environments and low-to-middle-income countries (LMIC), is not clear. This study aimed to perform a systematic review of the current literature and illustrate different types of MSUs and their uses, benefits, and limitations.

Methods: A PRISMA-compliant systematic review was conducted using PubMed, OVID Medline, CENTRAL, Embase, Scopus, and Web of Science from inception to April 2023. Studies evaluating MSU use in LMICs or austere environments were included. Two reviewers independently screened titles, abstracts, and full-text articles, with consensus achieved by a third reviewer. Data extraction and level of evidence assessment were performed using the Oxford Centre for Evidence-Based Medicine classification.

Results: Of 460 studies identified, 24 were included in the analysis. The most common MSU model was truck/bus-based (n=15, 62.5%), followed by portable models including the "SurgiBox™" sterile operative field. General surgery was the most common specialty (n=10, 41.7%), followed by obstetrics and gynecology (n=7, 29.2%). Main benefits included improved patient access, reduced wait times, and lower costs compared to conventional operating rooms. Limitations included crowding with increased surgical site infection risk (up to 14.3% in one study) and sustainability concerns. Study quality was poor, with 58.3% being case series (Level 4 evidence).

Conclusions: MSUs represent promising alternatives for providing surgical care in LMICs and austere environments. However, further research and improvement of MSU designs are required to enhance safety and reduce perioperative complications.

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Introduction

Surgically correctable conditions are reported to comprise one-third of the global disease burden[1]. The number of deaths from pathologies that are surgical in nature now surpasses that of the top Three infectious diseases: human immunodeficiency virus, tuberculosis, and

malaria[2]. Both the United Nations and the World Health Organization, as well as other international societies and governing bodies, are all highlighting the importance of equitable access to surgical care[3]. A prior systematic review that analyzed barriers to surgical care in LMIC found that the top three overarching categories limiting access include cultural, financial, and structural barriers[4]. Transportation to and from a preoperative appointment, the operating room, post-operative rehabilitation, and subsequent follow-up visits all pose a significant structural and financial barrier. Even in locations where a transportation infrastructure exists for patients to utilize, this non-medical cost of transportation to the patient has been shown to be prohibitive[5]. Mobile surgical units (MSUs), a type of medical facility that can be deployed rapidly, are a proposed partial solution that has demonstrated cost effectiveness and good outcomes. MSUs provide a method of delivering surgical care to remote or disaster-stricken regions via trucks, trains, trailers, planes, or other modes of travel. They are normally equipped with essential surgical tools, sterile environments, and staffed by highly trained individuals.

Austere surgical procedures are classified as a specific type of surgical modality utilized in areas with limited resources and/or capabilities. These practices date back thousands of years, as there is evidence of successful amputations among fossilized remains from the Neolithic time period, suggesting that early humans possessed a rudimentary understanding of surgical intervention, although it is not possible to determine whether these occurred due to desperation or deliberate strategy. Depending on the degree of flexibility with the term, this may represent the earliest examples of field surgery[6]

The concept of field surgery has evolved significantly over time, with significant improvements occurring in response to the demands of war and disaster. Ancient Greek and Roman civilizations documented their employment of designated personnel to perform surgical procedures near combat areas. The term “medici” was established by the Roman military to refer to an individual who would provide mobile medical care to the soldiers[7]

The more contemporary idea of an MSU had its foundation established during the Napoleonic Wars, as a French surgeon by the name of Dominique Jean Larrey introduced the “flying ambulance,” which was a horse-drawn carriage designated to evacuating wounded soldiers to a nearby area in order to be treated by medics. Morbidity and mortality were found to be markedly improved if rapid stabilization was provided closer to the time and point of injury. This led to the principles of rapid response and triage - principles that comprise the central doctrines of modern-day field surgery. During World War II, portable surgical hospitals (PSH) were introduced, which were small, compact mobile units that could easily be deployed with rapidly advancing frontlines on the battlefield. They had minimal infrastructure but highly trained medical personnel who would stabilize wounded soldiers to evacuate them to larger facilities. This establishment led to drastically reduced mortality rates and set the stage for the introduction of the Mobile Army Surgical Hospital (MASH) during the Korean War[8]. MASH units continued to improve their mobility, and with advanced surgical equipment and infrastructure, their effectiveness. Their operational efficiency remained in use through the Vietnam War and the beginning years of the Gulf War before they were replaced with newer systems such as Forward Surgical Teams (FSTs) and Combat Support Hospitals (CSHs)[8]. Today, the evolution of battlefield experiences has translated into more innovative means to reach the underserved in LMIC with poor health infrastructure, low surgeon density, and harder to reach remote populations[9,10].

The WHO emphasizes the importance of strengthening the local health system in addition to the traditional international surgical missions[11]. These missions are seen as a means of addressing the severe backlog of surgical cases in LMIC. However, despite the multitude of benefits that these missions provide, they have their limitations. For example, the presence of cultural barriers as well as the need for long-term follow-up are better addressed by a local surgeon. Mobile tents, trucks, buses, and trains have been described in the literature to meet the unique needs identified globally by these mission trips, and they are easier to maintain than the stationary traditional ORs

found in more developed countries. These mobile modalities of care were analyzed for their ability to provide broad diagnostic and therapeutic interventions as well as more narrow-scope treatments. Ultimately, there may be certain cases best addressed at larger tertiary centers. These decisions are left to the discretion of the deployed teams, highlighting the importance of adequate training and standardized protocols for referral in these areas. This study aimed to systematically review the literature and describe different types of MSUs, as well as their uses, benefits, and limitations.

Methods

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines and was registered in PROSPERO (CRD42022373427).

Search Strategy

A comprehensive search strategy was developed by an expert librarian (DS) using the Population, Exposure, Comparison, Outcomes and Study (PECOS) framework. Literature searches were conducted through PubMed, Embase, and CENTRAL databases from inception to April 2023. Primary keywords included "austere environments," "rural," "mobile operating rooms," and "portable surgical units." Medical Subject Headings (MeSH) and Emtree indexing terms were applied. Covidence software was used for data management and duplicate removal.

Eligibility Criteria

Two reviewers independently screened titles, abstracts, and full-text articles. Inclusion criteria comprised peer-reviewed original or review articles reporting MSU use. Conference abstracts, editorials, and comments were excluded. No publication year restrictions were applied.

Data Extraction and Quality Assessment

Two reviewers extracted the data and assessed the level of evidence for each study independently. Where the two reviewers disagreed, consensus was achieved by discussion with the third reviewer. Extracted data included the author names, study design, country, setting, MSU type, and reported advantages and limitations. A descriptive analysis of patient demographics was used. The Oxford Centre for Evidence-Based Medicine (OCEBM) classification was used to provide judgment about the level of evidence of the included studies.

Results

After duplicate removal, 430 articles were screened, with 30 remaining after title and abstract screening. Six studies were excluded during full-text review, leaving 24 studies for analysis (Figure 1).

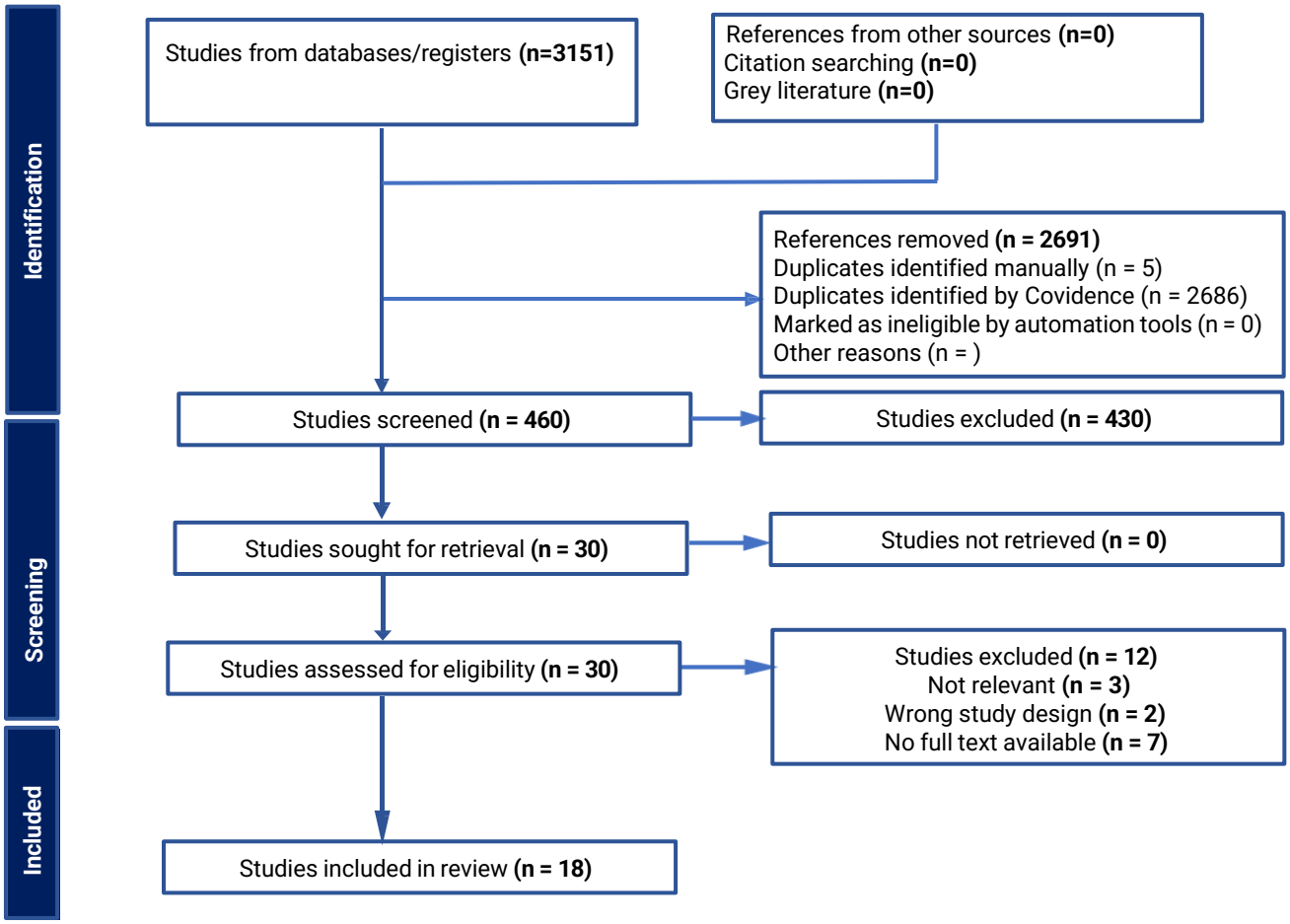
MSU Types and Distribution

Nine different MSU models were identified across the 24 studies. Truck/bus-based models were the most commonly described among the studies (n=15, 62.5%, Figure 2), followed by tents (n=2), ships (n=1), airplanes (n=1), trains (n=1), pre-existing facilities (n=1), and portable models (n=3). One such portable model that was mentioned was a portable bubble that serves as a sterile operative field named “SurgiBox™” - a compact system that involves a transparent surgical enclosure with glove ports and a filtration system to maintain sterility (Figure 3).

Surgical Specialities

General surgery was most commonly reported (n=10, 41.7%), followed by obstetrics and gynecology (n=7, 29.2%, Figure 4). Though its original purpose was for battlefield wounds, MSUs offer a promising dynamic model to address various surgical needs beyond trauma stabilization. A wide range of surgical conditions can be addressed with MSUs - ranging from general surgery hernia repair to more specialized operations such as cataract surgery and even minimally invasive percutaneous embolization procedures[16,17,18]. In addition to the obvious benefit of proximity of care to the patient, MSUs are attributed to reducing hospital wait times and avoiding complex referral systems that delay care for the local healthcare system. Local missions with trained staff in MSUs, in conjunction with other technologies such as telemedicine for follow up care, provide an efficient and cost-effective solution for improving access to surgical care. We look at examples of this model's implementation at addressing the shortage of essential, safe and affordable surgical procedures to more than half of the world’s population[19].

Figure 1: PRISMA Flow Chart



The most commonly reported benefit of MSUs was improvement of patient access, particularly for subspecialty care to rural areas (Figure 5). Some studies noted similar patient outcomes from MSUs compared to conventional hospitals and lower costs compared to conventional operating rooms, as well as increased utilization by minorities, specifically indigenous, female, and elderly populations. Another notable benefit of MSUs was the increased patient care capacity they provided for rural medical teams and decreased wait times. Increased trust in the surgery provided was also reported by patients in one study.

MSU's primary limitations are listed below:

- Crowding leading to increased surgical site infection risk (up to 14.3% in one study)
- Need for improved follow-up and cultural competency education
- Operational requirements varying by location, model, and specialty
- Dependency on existing hospital infrastructure or pre-existing buildings
- High expenses requiring private and government funding
- Limited staff and facility capabilities
- Equipment for elective and low-risk procedures only
- Lower imaging quality compared to standard hospitals
- Loss of sterility as operative days progressed

The broader concerns of long-term surgical outcomes and sustainability are not uniformly addressed; thus, further research needs to be conducted for analysis. An additional concern is to ensure a synergistic relationship between the MSUs and the pre-existing local medical resources[13]. This need for further research is of vital importance, as sufficient evidence must exist that indicates MSUs are a valuable investment to resource-limited health systems before their implementation[14].

One point to establish is that MSUs should not be considered to be a replacement to a government's local surgical system but rather should be used to help strengthen their expansion and improvement[15].

Figure 2: Truck-based MSU utilized in the remote region of Ecuador[20]

Figure 3: Use of Surgibox™ providing a sterile operating field[21]

Study Quality

Despite the decent number of studies identified by the systematic review, the overall quality of studies included was poor, with 58.3% of the studies having OCEBM Level 4 evidence (n=14), and the highest classification found was Level 3 (n=8). Case series were the most common type of study analyzed (n=14), followed by cross-sectional studies (n=7). No randomized controlled trials were identified. One animal experiment and one in silico modeling study were included. Eight studies had limited sample sizes (<150 patients).

Discussion

An MSU has historically been associated with a role in times of war, with large-scale implementation of its concept described in a multitude of military operations within the past few centuries. The portable surgical hospital (PSH) during the Second World War consisted of a small team of general surgeons and anesthetists with lightened versions of equipment that could be easily transported by military personnel. The advantage of these PSH when compared to the larger traditional field hospitals was the ability to bring surgical care closer to the frontlines. In the post-World War II era, the PSH was replaced by the larger Mobile Army Surgical Hospital (MASH), which allowed for more complex levels of care. However, the emphasis on a higher level of mobility has recently returned within the past few decades, which is reflected using a medical detachment or forward surgical team, a subtype of the MSU[3]. Out of the different types of MSUs, the truck seemed to be favored for its convenience, rapid deployability, and all-terrain capability, which allows for care closer to patient homes[12].

MSUs not only have been shown to have benefits in battlefield circumstances but also have more broadly demonstrated notable achievements in global health. The Lancet Commission on Global Surgery describes access to safe, affordable surgical and anesthetic care as a pressing matter in global health, most recently describing upwards of five billion people being affected by this issue. MSUs are proving to be of significant utility in addressing this problem, as their transportable design can provide surgical care in locations where permanent medical infrastructure is unavailable or impractical. To our knowledge, this is the first systematic review of the current literature describing experiences and outcomes of the implementation of mobile surgical units across the world.

In this review, we were able to compile multiple accounts and studies of MSUs being successfully established in a wide range of environments where access to surgery has otherwise been largely lacking[8-18]. Surgical services become more easily attainable for various underserved populations who have a limited ability to travel distances[10].

Figure 4: The distribution of types of surgical specialties.

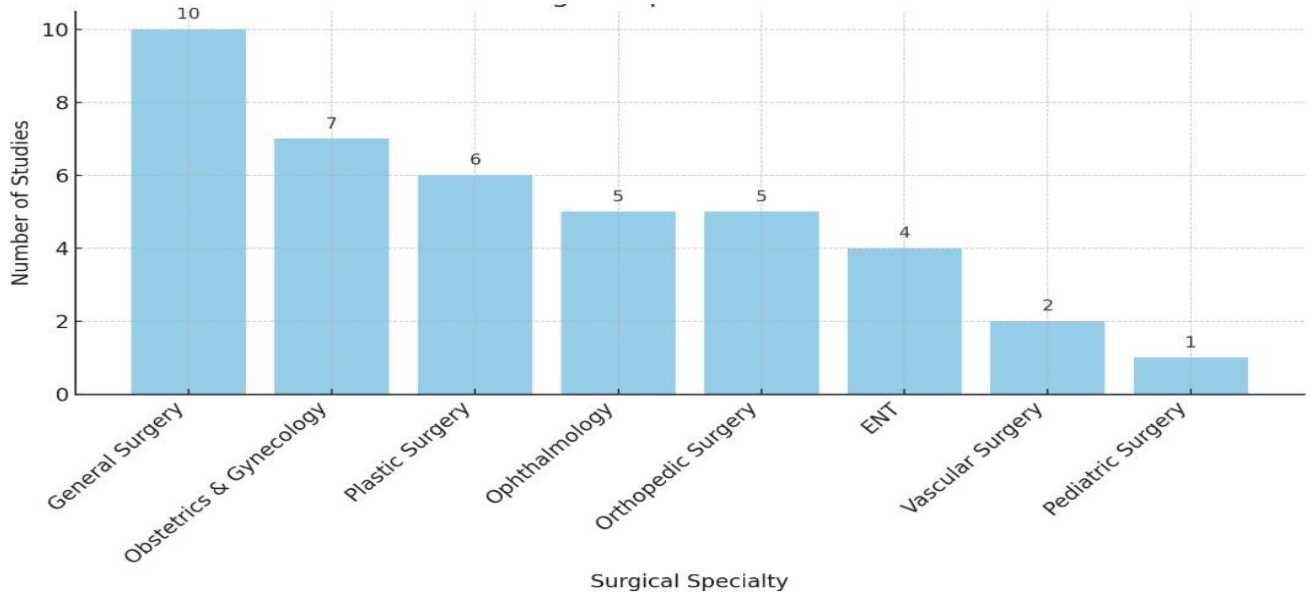
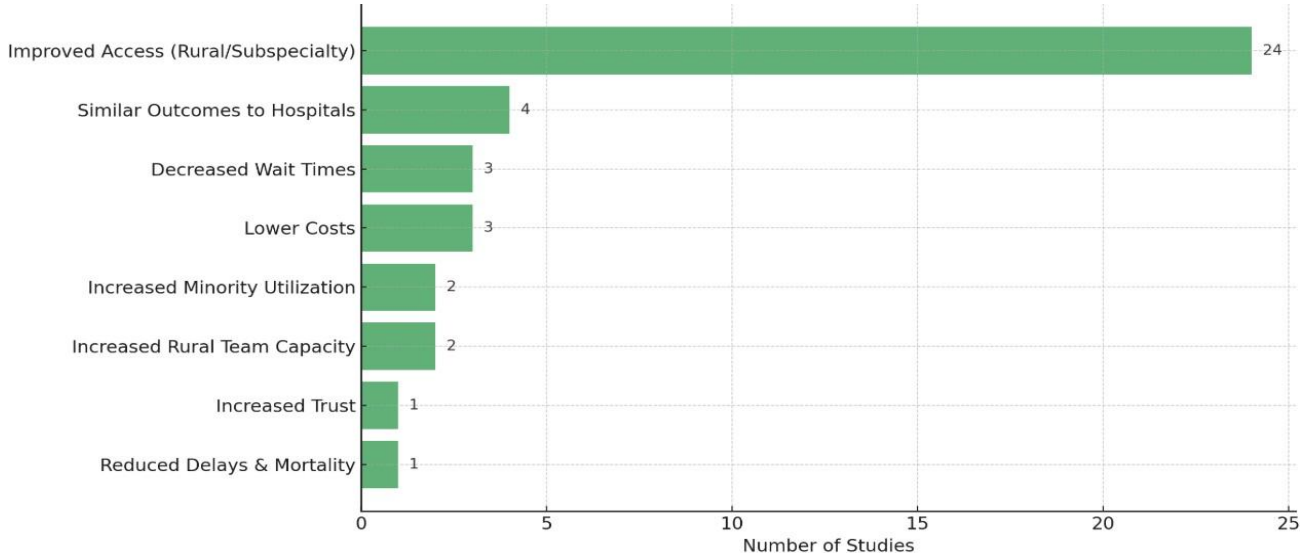


Figure 5: Reported benefits of MSU utilization



Despite transportation being possible for some, surgical care in a larger city can still be associated with lengthy wait times lasting as long as several weeks to months, which poses an additional layer of difficulty for many[2,4,20]. The overall cost to operate an MSU was not prohibitive and was described to be comparable to that of a conventional hospital operating room[2].

Literature included in this review not only provided descriptive details on how various mobile operating suites are built and configured, but they additionally offer insight on potential concerns with the use and operational capacities of MSUs. The issue of whether mobile surgery units are inferior to fully equipped hospitals is a question addressed by some studies in the current literature. Some authors have been able to demonstrate that teams operating in MSUs can achieve similar results for a variety of surgical procedures when compared to established hospitals' outcomes. Two reasons behind their success that are offered by these studies involve adherence to aseptic surgical technique and skills of the operating surgeon[1,22].

While the modern operative theater offers technological advancements that provide a sterile, sophisticated suite, there are core fundamentals of the aseptic technique in surgery that should be adhered to, regardless of the circumstances. They can still be maintained while becoming condensed into a setup that allows performing surgical procedures in more austere environments. This is

seen in the results of multiple reports, which describe low complication rates, including surgical site infections[1,5,13,16]. Thus, the design of an MSU should involve consultation with an OR architect and the MSU team, which includes a surgeon, technicians, and anesthetist. Despite having the potential to provide a sterile operative unit, many authors do recognize that increased incidence of wound infections can be a potential concern, especially in circumstances that create difficulties in proper cleaning techniques. One such example is a study that described having four surgical beds in a single operating theater in their MSU in Thailand[1]. This study brought into account the idea that it would be beneficial to take an evidence-based approach at determining the minimum safe distance between surgical fields that does not compromise OR sterility, particularly for austere environments where space is limited. However, because this is not an issue encountered in the modern OR, there is very limited research regarding this issue. Related to this concern, unique equipment such as the SurgiBox™ has been introduced currently as proof-of-concept. Such technology may augment the ability of an MSU to provide quality surgical care in LMICs[26].

It is then reasonable to expect standard outcomes from surgery, given that the procedures are being performed by a licensed surgeon who is competent with a set range of operations. There is an increasing interest in global surgery among foreign trainees, many of whom seek out experiences operating in LMICs while in earlier parts of their career, which by extension means that these individuals may find opportunities to join an MSU. With this increasing interest and participation, trainees must be aware of certain ethical considerations. Grant and colleagues outlined a set of ethics domains in the practice of global surgery[22]. Two ethical themes described include (1) performing procedures outside of the scope of one's training; and (2) settings where supervision of trainees is limited and disproportionate to their relative skill level[22]. To avoid compromising the quality of patient care, the successful use of MSUs is contingent on deploying surgeons who are actively practicing and are appropriately licensed within their specialty, as well as providing a level of supervision to trainees that is equal to the standards expected in higher-income countries. One weakness noted in the literature was limited data for follow-up, often describing shorter than average periods of follow-up for patient care. Thus, the long-term results of these patients are unclear[1,13]. To combat this knowledge gap, advocates for global surgery have called for not only the implementation of but also a mandate for reporting patient outcomes. The WHO is currently working to build upon the standardized mechanisms for long-term data collection to help assess outcomes in a similar quality as seen with the United States' NSQIP[23]. It is worth noting that some authors were able to arrange plans for follow-up as far as one year out from surgery[2,4,26]. Small sample size is another weakness noted in multiple of the included studies[2,16,17,18].

Finally, it should be mentioned that mobile surgical units are not described as a replacement to more traditional means of surgical infrastructure, which refers to a conventional hospital or surgical center. Rather, MSUs aim to help "fill the gap" and provide an alternative solution for the provision of surgical care to communities living in more austere and/or remote environments.This systematic review has several limitations. The overall quality of included studies was poor, with most being case series providing Level 4 evidence. The lack of randomized controlled trials limits the strength of conclusions. Heterogeneity in MSU types, settings, and outcome measures precluded meta-analysis. Publication bias may exist, as successful MSU implementations may be more likely to be reported than failures.

This comprehensive review emphasizes MSU potential for expanding surgical care in LMICs whilst maintaining the standards of modern operating rooms. MSUs represent excellent alternatives for providing surgical care in LMICs and austere environments; however, further research and improvement of its utilization are required to improve safety and reduce perioperative complications. Future studies should focus on standardized outcome measures, long-term follow-up protocols, and cost-effectiveness analyses to better establish MSU value in delivery of surgical care to these populations.

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