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ORIGINAL ARTICLE

Locally led, globally impactful: a simulation-based laparoscopic skills curriculum in Ethiopia

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Abstract

Purpose Access to laparoscopic surgery is severely limited across much of sub-Saharan Africa, where formal training infrastructure is scarce, and most programs depend on visiting foreign faculty. We evaluated whether a short, locally led, simulation-based laparoscopic curriculum delivered entirely by in-country faculty and resources could improve the laparoscopic knowledge and technical skills of practicing surgeons and surgical residents in Ethiopia.

Methods Thirty participants (14 surgeons; 16 surgical residents) with no prior formal laparoscopic instruction were enrolled in a blended curriculum: 6 weeks of asynchronous online modules based on the Fundamentals of Laparoscopic Surgery (FLS) framework, followed by a 5 day intensive hands-on workshop delivered by in-country faculty using both locally fabricated and commercially available box trainers. Three FLS-based tasks (peg transfer, precision cutting, and intracorporeal suturing) were timed before and after training; a nine-domain Global Rating Scale (GRS; maximum 45) and a 20-item multiple-choice knowledge test were also administered. Paired-samples *t*-tests, McNemar tests, Pearson correlation, and linear regression were used; effect sizes were estimated using Cohen's d or Hedges' g.

Results Twenty-eight of the 30 participants completed both assessments and were analyzed. All task completion times decreased significantly: peg transfer from 5.51 to 2.47 min, precision cutting from 5.74 to 3.17 min, and suturing from 10.95 to 3.71 min (all $p < 0.001$; effect sizes 0.94–1.26). GRS scores rose from 17.8 to 30.1 (+12.3 points; $p < 0.001$; d = 1.49), with 27 of 28 participants (96%) improving. Knowledge scores rose modestly, from 13.5 to 15.5 out of 20 (mean gain 2.0; n = 30; $p = 0.003$). Both surgeons and residents improved significantly in technical skill ($p = 0.001$ and $p < 0.001$, respectively), and the magnitude of improvement did not differ significantly between the two groups. In exploratory analyses, baseline knowledge was associated with baseline skill (r = 0.49; $R^2 = 0.24$; $p < 0.01$) but not with post-training skill (r = −0.03; $p = 0.87$).

Conclusions A brief, intensive, locally led blended curriculum produced large and consistent improvements in laparoscopic skills in a low-resource setting. Prior theoretical knowledge was associated with technical skill before training but not after it, an exploratory observation suggesting that structured hands-on practice may reduce the influence of prior theoretical preparation. Post-training times remained above published FLS proficiency benchmarks, so the curriculum should be regarded as establishing foundational skills rather than certification-level proficiency. These findings support locally owned, replicable models of surgical capacity building as a sustainable strategy to expand minimally invasive surgery in the Global South.

Keywords Laparoscopy · Simulation-based training · Surgical education · Global surgery · Low- and middle-income countries · Capacity building

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Introduction

Over recent decades, the global burden of disease has shifted from predominantly communicable illness toward injury and non-communicable conditions, an estimated one third of which is amenable to surgical care [1]. Despite this, the Lancet Commission on Global Surgery estimated that approximately five billion people lack access to safe, timely, and affordable surgical care, a deficit concentrated overwhelmingly in low- and middle-income countries (LMICs); without substantial investment, surgically treatable conditions are projected to impose trillions of dollars in economic losses by 2030 [2, 3]. Closing this gap requires not only infrastructure and financing but a trained surgical workforce capable of delivering modern operative care.

Minimally invasive surgery is central to this agenda. Laparoscopy lowers surgical site infection, postoperative pain, and length of stay while hastening return to work, advantages that are magnified where hospital beds are scarce and many patients are sole household earners who cannot afford prolonged recovery [4]. Yet laparoscopic adoption in LMICs lags far behind high-income countries, constrained by intersecting health-system and financial barriers, the most persistent of which is a shortage of surgeons and surgical residents with structured laparoscopic skills training [4–6]. In Ethiopia, laparoscopic services and the skills laboratories needed to build them remain concentrated in a small number of large urban centers.

Simulation-based education offers a pragmatic remedy. The Fundamentals of Laparoscopic Surgery (FLS) program, which pairs a cognitive curriculum with standardized manual tasks such as peg transfer, pattern cutting, and intracorporeal suturing, has become the benchmark for laparoscopic competence and can be taught using inexpensive trainers [7]. Short simulation courses have produced meaningful skill gains in LMICs, including earlier work with surgical residents in Ethiopia [8]. Historically, however, many such programs have relied on a visiting-faculty or short-mission model in which expertise is imported and continuity depends on external teams. As global surgery reorients from this model toward partnership and local ownership, a central question remains unanswered: can high-quality laparoscopic training be delivered effectively by local faculty, using locally available and locally fabricated resources, without reliance on foreign instructors or imported equipment?

We implemented and evaluated a locally led, simulation-based laparoscopic skills curriculum for practicing surgeons and surgical residents in Addis Ababa, Ethiopia, designed, delivered, and assessed entirely by in-country faculty. No international or visiting faculty participated in the conception, implementation, delivery, or evaluation of the course. We hypothesized that a short, intensive, blended FLS-based curriculum would significantly improve laparoscopic knowledge and technical skill, and we further examined whether prior theoretical knowledge predicted technical performance before and after training, to clarify the relative contributions of cognitive preparation and hands-on practice to skill acquisition.

Methods

Study design

This was a single-group, pre–post interventional study of a simulation-based laparoscopic skills curriculum. Participants served as their own controls, with a paired assessment of knowledge and technical performance immediately before and after the intervention. Reporting follows the principles of the STROBE statement for observational research as applicable to a single-arm educational intervention.

Setting

The curriculum was developed and delivered in Addis Ababa, Ethiopia, by a locally led, surgeon-founded nonprofit organization dedicated to expanding minimally invasive surgery training and research in the region. The online component was delivered asynchronously; the hands-on workshop was conducted at a regional simulation venue using both commercially available and locally fabricated trainers. All faculty were in-country surgeons; the program did not rely on visiting foreign instructors.

Participants, inclusion and exclusion criteria

Eligible participants were practicing surgeons and surgical residents who had no prior formal, structured laparoscopic training. Candidates were required to attend and complete an online introductory session prior to enrollment; those who did not complete this session were excluded. Thirty surgical trainees were enrolled, comprising 14 general and pediatric surgeons and 16 general surgery and urology residents. Participation was voluntary, and all participants provided informed consent. Twenty-eight of the 30 participants completed both the pre- and post-training skill assessments and were included in the technical-skill and Global Rating Scale analyses; all 30 completed the written knowledge assessment. Participant flow is presented in Supplementary Fig. S1. No a priori sample size or power calculation was performed. The study was an evaluation of a single training course, and all individuals who met the eligibility criteria

during the recruitment of participants using a conventional sampling method.

Curriculum design

The intervention was a blended curriculum combining a structured online didactic phase with an intensive in-person skills phase, modeled on the FLS framework [10, 11].

Over six weeks preceding the workshop, participants completed asynchronous online modules based on the FLS cognitive curriculum, covering the principles of laparoscopic access, energy devices, instrumentation, optics, and the rationale and mechanics of the core manual tasks. The online phase standardized baseline theoretical exposure across a cohort with heterogeneous prior experience.

The online phase was followed by a five-day intensive, supervised hands-on workshop. Training emphasized deliberate, repetitive practice of three core FLS tasks with structured feedback, progressing from task familiarization to timed proficiency-oriented repetition.

The simulation-based training was conducted in collaboration with Minimally Invasive Surgery Africa (MIS Africa), an organization that regularly conducts laparoscopic surgery training using simulation-based approaches. The training faculty comprised experienced laparoscopic surgeons and trainers affiliated with MIS Africa. A total of 30 trainees participated in the five-day hands-on workshop, which comprised a baseline assessment session, supervised deliberate practice, and a post-training assessment session. All participants completed the online training module before commencing the practical component. During the five days of practical training, participants were provided unrestricted opportunities to practice the designated laparoscopic tasks using both locally fabricated and commercially available laparoscopic trainers. No fixed practice duration or minimum number of repetitions was prescribed, allowing participants to continue practicing until they felt confident performing the assigned tasks. Five in-country laparoscopic faculty supervised the workshop, giving a faculty-to-learner ratio of approximately 1:6. All faculty were practicing laparoscopic surgeons with a minimum of five years of laparoscopic operative experience, and all were based in Ethiopia; no international or visiting faculty took part in the design, delivery, or assessment of the course. Faculty provided direct observation, verbal feedback, correction of technical errors, and demonstration of appropriate technique when required. Feedback was delivered both during task performance, as real-time coaching, and after task completion, as a structured debriefing; no feedback or coaching was provided during the pre- or post-training assessments. No minimum number of repetitions and no proficiency target or pass/fail threshold were set for practice.

Box trainer construction

The workshop used two categories of simulators in parallel. Six locally fabricated box trainers were constructed in-house from low-cost, locally sourced materials, designed to fit personal mobile devices as a camera and monitor to reproduce the closed laparoscopic working environment. Three imported commercially available laparoscopic surgery training boxes (Laparoskopisch Trainer Box; ASIN B09XF5RKPZ) each with a USB HD camera, adjustable LED lighting, silicone access pad, and multiple instrument insertion ports, were used alongside the locally fabricated trainers. The manufacturer was not identifiable from the product documentation available to the investigators. The photographs and the design process of the locally fabricated trainers are provided in Supplementary Fig. S2. Using both platforms in parallel allowed the course to be delivered to 30 participants with only three imported units; the study was not designed to compare the two platforms, and no inference about the relative effectiveness or equivalence of locally fabricated and commercially available trainers can be drawn from these data.

All 30 participants had access to and practiced on both the locally fabricated and commercially available laparoscopic trainers during the hands-on training period. The two trainer platforms were therefore used as complementary components of the same training curriculum rather than as separate intervention groups. Participants were not randomized or assigned to a specific trainer platform, and practice time or number of repetitions on each platform was not prospectively standardized. Consequently, outcomes were analyzed for the training program as a whole rather than compared between trainer platforms.

Outcome measures and assessments

Outcomes were assessed before and after the curriculum using three complementary instruments: timed technical task performance, a structured global rating of operative skill, and a knowledge test.

Technical skill tasks

Three FLS-based standardized tasks were evaluated: peg transfer, precision cutting, and intracorporeal suturing. Peg transfer was scored on six elements (grasping a peg with the non-dominant hand, mid-air transfer to the dominant hand, accurate placement on the opposite post, repetition for all pegs, completion without dropping pegs, and completion time). Precision cutting was scored on six elements (grasping the material with the non-dominant instrument, initiating the cut on the marked circle, following the line

accurately, completing the full circle, completing the task without tearing or excessive deviation, and completion time). Intracorporeal suturing was scored on seven elements (correct needle loading, precise needle placement through both targets, adequate tissue depth, proper suture handling, secure square knot, completion without tissue trauma, and completion time). Categorical elements were recorded as success or failure; completion time was recorded for each task.

Global Rating Scale

Overall operative performance was assessed with a nine-domain Global Rating Scale adapted from established objective structured assessment of technical skill instruments [9, 10]. The full instrument, including the descriptive anchors for each domain, is provided as Supplementary Table S1. Domains comprised respect for tissue, time and motion, instrument handling, use of both hands, flow of operation, depth perception, camera control, knowledge of the procedure, and overall performance, each scored from 1 to 5 for a maximum total of 45.

The assessment incorporated standardized FLS tasks and predefined task-specific performance elements; however, it was not intended to replicate the formal FLS certification/proficiency assessment. The official FLS proficiency time limits, repetition requirements, and proficiency thresholds were not applied. Completion time was recorded for each task as a continuous performance measure, but no maximum completion time or time-based pass/fail criterion was imposed. Categorical task elements were recorded as successful or unsuccessful, and no additional numerical penalty points were assigned for errors. Performance was evaluated based on changes in task performance before and after the training intervention. Participants were permitted to practice the designated tasks throughout the training period without a predefined maximum number of attempts.

Global Rating Scale assessments were performed by evaluators with ≥ 5 years of experience in minimally invasive/laparoscopic surgery. Although some evaluators were involved in training the participants, they did not participate in the assessment session on the examination day. Assessment recordings did not contain participants' faces or other directly identifiable information. Recordings were assigned study codes by the study organizers, who retained the code key, and the coded recordings were subsequently distributed to the evaluators for scoring. Evaluators did not have access to the code key and were blinded to participant identity and to whether each recording represented a pre-training or post-training assessment. Inter-rater reliability was not formally assessed.

Knowledge assessment

Theoretical knowledge was assessed with a 20-item multiple-choice test (maximum score 20) administered before and after the curriculum.

Statistical analysis

Continuous outcomes (task completion times, GRS totals, and knowledge scores) were compared between the pre- and post-training assessments using paired-samples *t*-tests, with 95% confidence intervals (CIs) reported for mean differences. Categorical task elements were compared using McNemar tests for paired proportions. The relationship between knowledge and technical performance was examined with Pearson correlation and confirmed with Spearman correlation; simple linear regression was used to quantify the extent to which knowledge predicted GRS performance before and after training, reported as the unstandardized coefficient (B) and coefficient of determination (R^2). Effect sizes were estimated using Cohen's d or Hedges' g and interpreted using conventional thresholds (0.2 small, 0.5 medium, 0.8 large). Differences between surgeons and residents were tested by comparing individual change scores (post-training minus pre-training) between the two groups using an independent-samples *t*-test; this comparison is equivalent to the group × time interaction term of a mixed analysis of variance and is the test used to determine whether the magnitude of improvement differed by professional role. Within-group pre–post tests are reported descriptively and are not used to infer between-group differences. Analyses of individual categorical task elements and of subgroups defined by professional roles were not specified a priori, were not powered, and were not adjusted for multiplicity; these analyses are reported as exploratory and hypothesis-generating. The non-parametric Wilcoxon signed-rank test was used to corroborate the paired *t*-test for the GRS. A two-sided *p*-value below 0.05 was considered statistically significant.

Ethical considerations

This study was approved by the Johns Hopkins University School of Medicine Institutional Review Board (Office of Human Subjects Research Institutional Review Boards; approval number IRB00442182). The protocol was additionally submitted to the Institutional Ethics Review Committee of Myungsung Medical College (MMC)/MCM Comprehensive Specialized Hospital, Addis Ababa, the host institution for the training program. The Committee reviewed the protocol and determined that, because the study involved a voluntary educational training activity with no patient

Table 1 Participant characteristics (N = 30)

Characteristic	Category	n (%)
Profession	General/pediatric surgeons	14 (46.7)
	Residents (general surgery and urology)	16 (53.3)
Sex	Female	4 (13.3)
	Male	26 (86.7)
Years of surgical experience	< 1 year	3 (10.0)
	1–4 years	25 (83.3)
	> 4 years	2 (6.7)
Prior exposure to minimally invasive procedures	Yes (assisted or performed)	28 (93.3)
	No	2 (6.7)
Age, years	Mean (range)	32 (28–38)

participation and no clinical intervention, and collected only de-identified assessment data from consenting professional participants under an existing Johns Hopkins University IRB approval, no separate local ethical approval or additional institutional authorization was required. Institutional permission to conduct the training and the associated assessments at the host site was granted. All participants provided written informed consent before enrollment, and all assessment data were de-identified before analysis.

Results

Participant characteristics

Thirty participants were enrolled, all of whom had completed the online introductory session; no participants were excluded because of non-completion of the online module. The cohort comprised 14 surgeons (46.7%) and 16 surgical residents (53.3%). Most participants were male (26; 86.7%), and the mean age was 32 years (range 28–38). The majority had 1–4 years of surgical experience (25; 83.3%), and 28 (93.3%) had previously assisted with or performed a minimally invasive procedure, although none had received formal structured laparoscopic training. Of the 30 enrolled participants, 28 completed both the pre- and post-training assessments and were included in the analysis. (Table 1).

Knowledge outcomes

Overall knowledge scores improved significantly after training, rising from 13.53 ± 2.78 to 15.57 ± 2.47 out of 20 (mean difference +2.04; t(29) = 3.18; $p = 0.003$), with a medium effect size (Cohen's d = 0.58). Twenty of 30 participants (66.7%) improved their knowledge score.

Task performance outcomes

Technical performance improved markedly across all three FLS tasks, with large effect sizes and reductions in completion time of approximately 53% to 65% (Table 2 and Fig. 1).

Peg transfer

Mean completion time decreased from 5.51 ± 2.78 to 2.47 ± 0.82 min (mean reduction 3.04 min; 95% CI 2.09–3.98; t(27) = 6.58; $p < 0.0001$; Cohen's d = 1.24), and 24 of 28 participants (85.7%) improved. Among the categorical elements, statistically significant gains were observed in mid-air transfer of the peg to the dominant hand ($p = 0.039$) and completion without dropping pegs ($p = 0.001$); the remaining elements (non-dominant grasp, accurate placement, and repetition across all pegs) did not change significantly (p = 1.00, 0.092, and 1.00, respectively).

Precision cutting

Mean completion time decreased from 5.74 ± 2.84 to 3.17 ± 1.35 min (mean reduction 2.57 min; 95% CI 1.53–3.62;

Table 2 Pre- and post-training performance for the overall cohort

Task	Metric	Pre-training (M ± SD)	Post-training (M ± SD)	Mean diff	Improved, n (%)	t (df)	p; effect size
Peg transfer	Time (min)	5.51 ± 2.78	2.47 ± 0.82	−3.04	24/28 (85.7)	6.58 (27)	< 0.0001; d = 1.24
Precision cutting	Time (min)	5.74 ± 2.84	3.17 ± 1.35	−2.57	23/28 (82.1)	5.06 (27)	< 0.001; g = 0.94
Suturing	Time (min)	10.95 ± 5.54	3.71 ± 1.23	−7.14	26/28 (92.9)	6.75 (27)	< 0.001; d = 1.26
Global Rating Scale	Total (max 45)	17.75 ± 8.82	30.07 ± 8.93	+12.32	27/28 (96.4)	8.06 (27)	< 0.001; d = 1.49
Knowledge	Total (max 20)	13.53 ± 2.78	15.57 ± 2.47	+2.04	20/30 (66.7)	3.18 (29)	0.003; d = 0.58

M, mean; SD, standard deviation; diff., difference. Task completion times are reported in minutes. Task completion time and Global Rating Scale outcomes were analyzed for the 28 participants who completed both the pre- and post-training skills assessments; the knowledge outcome was analyzed for all 30 enrolled participants, all of whom completed both knowledge assessments. Negative mean differences indicate faster (improved) completion times. Effect size: Cohen's d or Hedges' g

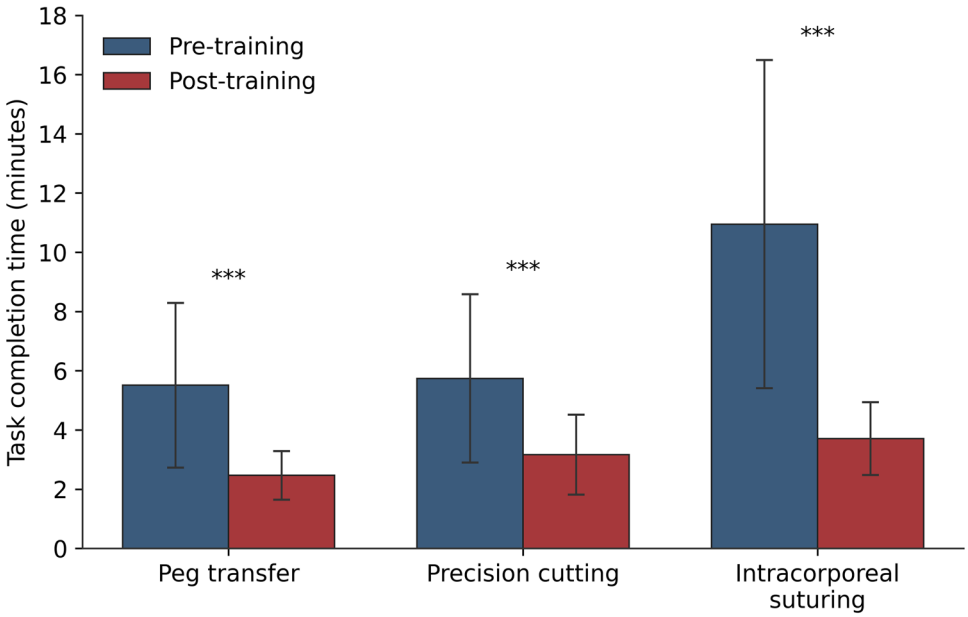


Fig. 1 Pre- and post-training completion times for the three fundamentals of laparoscopic surgery tasks. Bars show mean completion time in minutes for peg transfer, precision cutting, and intracorporeal suturing before (dark) and after (light) training; error bars represent standard deviation. ***$p < 0.001$ by paired-samples *t*-test

t(27) = 5.06; $p < 0.001$; Hedges' g = 0.94), and 23 of 28 participants (82.1%) improved. Significant categorical gains were observed in following the line accurately and completing the task without tearing or excessive deviation (both $p < 0.001$), with no participant regressing on either element; the remaining elements (grasping the material with the non-dominant instrument, initiating the cut on the marked circle, and completing the full circle) did not change significantly ($p = 1.00$ for all).

Intracorporeal suturing

Suturing showed the largest absolute change, with mean completion time falling from 10.95 ± 5.54 to 3.71 ± 1.23 min (mean reduction 7.14 min; 95% CI 4.97–9.30; t(27) = 6.75; $p < 0.001$; Cohen's d = 1.26), and 26 of 28 participants (92.9%) improved. Significant categorical gains were observed in correct needle loading ($p = 0.001$), precise needle placement through both targets ($p = 0.013$), adequate tissue depth ($p = 0.039$), and proper suture handling ($p < 0.001$). Two elements, suturing without tissue trauma ($p = 0.146$) and securing a square, non-loose knot ($p = 0.096$), did not reach significance.

Global Rating Scale outcomes

GRS total scores improved substantially, from 17.75 ± 8.82 to 30.07 ± 8.93 out of 45 (mean difference +12.32; t(27) = 8.06; $p < 0.001$), with the largest effect size of any outcome (Cohen's d = 1.49). Twenty-seven of 28 participants (96.4%) improved and only one declined. The non-parametric Wilcoxon signed-rank test corroborated this result (Z = −4.39; $p < 0.001$). Pre- and post-training GRS distributions are shown in Fig. 2.

Subgroup analysis by role

Surgeons and residents showed distinct learning profiles (Table 3 and Fig. 2b). Among the 14 surgeons, both knowledge (13.50 ± 2.93 to 16.71 ± 1.77; $p = 0.002$; |d|=1.0) and GRS performance (16.50 ± 7.90 to 27.93 ± 8.87; $p = 0.001$; |d|=1.19) improved significantly, with large effect sizes in both domains. Among residents, GRS performance improved markedly (19.00 ± 4.54 to 32.21 ± 7.43; $p < 0.001$; |d|=1.72), whereas the change in knowledge was small and non-significant (13.56 ± 2.73 to 14.56 ± 2.62; $p = 0.271$; |d|=0.29). Formal between-group comparison of individual change scores, however, showed no significant difference between surgeons and residents in the magnitude of improvement in either Global Rating Scale score (mean change +11.43 versus +13.21; t(26) = −0.54; $p = 0.59$) or knowledge score (mean change +3.21 versus +1.00; t(26) = 1.76; $p = 0.09$) (Fig. 3).

Relationship between knowledge and technical skill

Before training, knowledge was moderately positively associated with GRS performance (Pearson r = 0.493; $p < 0.01$) (Fig. 4). Linear regression showed that baseline knowledge was significantly associated with baseline GRS, with each one-point increase in knowledge corresponding to a 1.12-point higher GRS score (B = 1.12; $p = 0.007$; $R^2 = 0.24$; adjusted $R^2 = 0.21$). After training, the association between post-training knowledge and post-training GRS was negligible and non-significant (Pearson r = − 0.033; Spearman

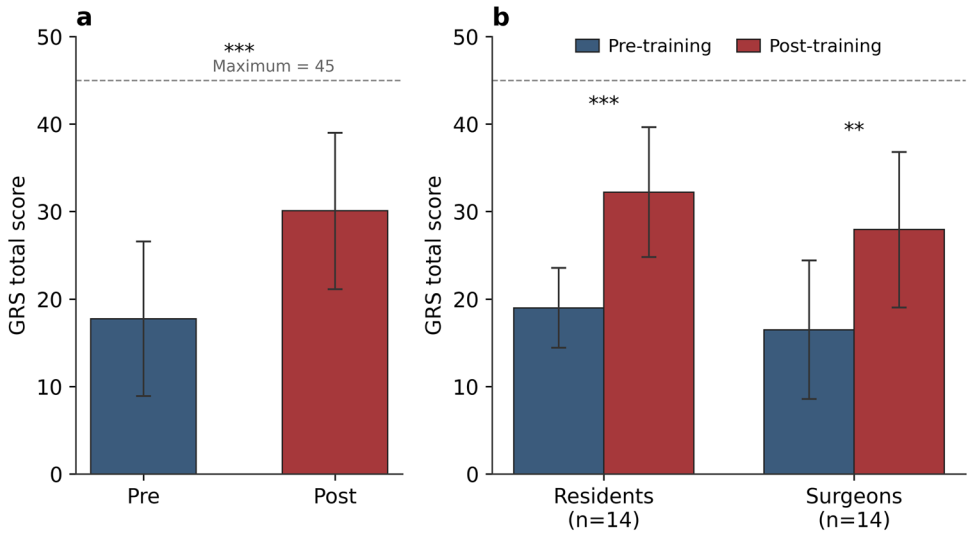


Fig. 2 Global Rating Scale (GRS) total scores before and after training. **a** Overall GRS total score (maximum 45) for the full cohort, pre- and post-training. **b** GRS total score by role for residents and surgeons. Bars show means and error bars represent standard deviation; the dashed line marks the maximum attainable score. $^{**}p < 0.01$; $^{***}p < 0.001$ by paired-samples *t*-test

Table 3 Subgroup analysis of knowledge and Global Rating Scale outcomes by role

Group	Variable	Pre-training (M ± SD)	Post-training (M ± SD)	Cohen's d	p
Residents (n = 14)	Knowledge (max 20)	13.56 ± 2.73	14.56 ± 2.62	0.29	0.271
	GRS (max 45)	19.00 ± 4.54	32.21 ± 7.43	1.72	< 0.001
Surgeons (n = 14)	Knowledge (max 20)	13.50 ± 2.93	16.71 ± 1.77	1.00	0.002
	GRS (max 45)	16.50 ± 7.90	27.93 ± 8.87	1.19	0.001

GRS, Global Rating Scale. Effect sizes are reported as absolute values of Cohen's d for the paired pre–post comparison within each group

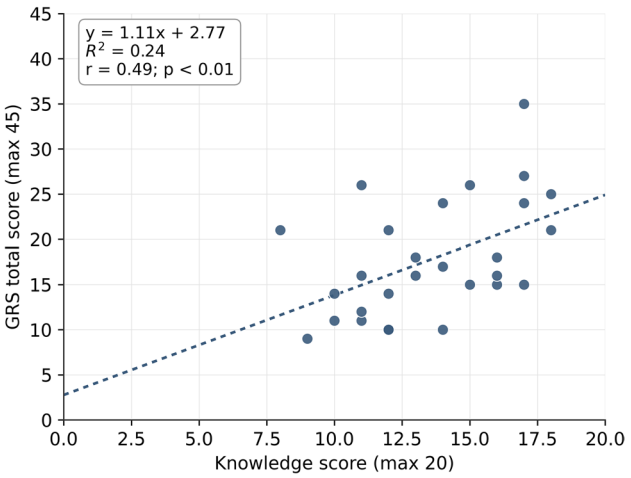


Fig. 3 Correlation between knowledge and GRS performance before training. Scatterplot of pre-training GRS total score against pre-training knowledge score for the full cohort, with the fitted linear regression line (dashed)

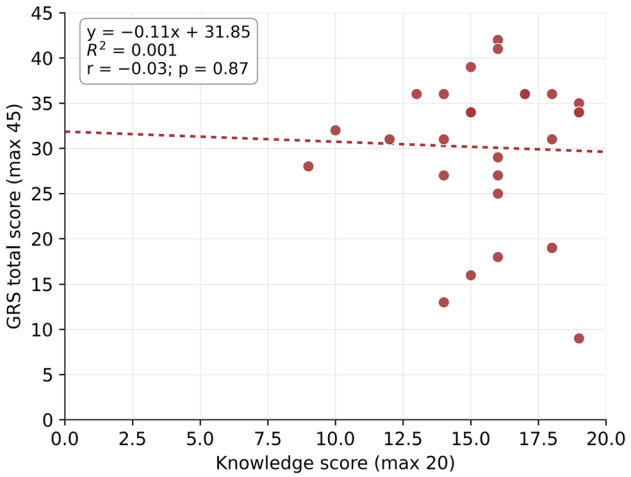


Fig. 4 Correlation between knowledge and GRS performance after training. Scatterplot of post-training GRS total score against post-training knowledge score for the full cohort, with the fitted linear regression line (dashed)

ρ = 0.080; both $p > 0.05$), and post-training knowledge was not significantly associated with post-training GRS (B = −0.11; $p = 0.866$; $R^2 = 0.001$). These findings suggest, but do not establish, a change in the relationship between knowledge and technical performance following training and should therefore be considered exploratory (Table 4).

Discussion

In this study, we inquired whether a short, locally led, simulation-based laparoscopic curriculum could meaningfully improve the skills of surgeons and residents in a low-resource setting using local faculty and resources. The answer was unequivocal. Across all three core FLS tasks, completion times fell by approximately 53% to 65%, and

Table 4 Correlation and regression between knowledge and GRS performance, before and after training

Assessment time	Pearson r (p)	Regression B (p)	R^2 (adjusted R^2)
Pre-training	0.493 ($p < 0.01$)	1.12 ($p = 0.007$)	0.24 (0.21)
Post-training	−0.033 ($p > 0.05$)	−0.11 ($p = 0.866$)	0.001 (<0.001)

GRS, Global Rating Scale; B, unstandardized regression coefficient; R^2, coefficient of determination. The regression coefficient B represents the change in GRS score per one-point change in knowledge score

overall operative performance on the GRS rose by more than 12 points, with 27 of 28 participants improving. Effect sizes ranged from 0.94 to 1.49, placing the magnitude of skill gain at the upper end of what simulation-based surgical education typically achieves. That these gains were produced by an entirely in-country team, using both locally fabricated and commercially available trainers, indicates that high-quality laparoscopic training is achievable in Ethiopia without dependence on visiting foreign faculty or exclusively imported equipment.

These gains should be interpreted as improvement relative to each participant's own baseline rather than as attainment of a formal proficiency standard. Mean post-training completion times, 2.47 min for peg transfer, 3.17 min for precision cutting, and 3.71 min for intracorporeal suturing, remained approximately two- to threefold longer than published FLS proficiency benchmarks of 48, 98, and 112 s, respectively [7]. The curriculum was designed and delivered as an introductory course intended to establish foundational laparoscopic skills in learners with no prior structured training, and neither its duration nor its assessment protocol was intended to bring participants to FLS certification-level proficiency; official FLS time limits, repetition requirements, and proficiency thresholds were not applied. Sustained deliberate practice beyond the workshop would be required to approach those benchmarks.

Two additional findings enrich this picture. First, the exploratory subgroup analysis suggested distinct learning profiles by experience: surgeons improved significantly in both knowledge and technical skill, whereas residents achieved their largest gains in skill, although the between-group comparison of change scores did not reach statistical significance for either outcome. Second, and most novel, baseline theoretical knowledge was moderately associated with baseline technical performance yet showed no significant association with technical performance after training. This exploratory observation is consistent with, though it does not establish, a curriculum that reduces the influence of prior theoretical preparation and brings learners of differing theoretical backgrounds to a more comparable and substantially higher level of performance.

These results sit within a well-established evidence base. Since its introduction in the 1980s, laparoscopy has expanded rapidly worldwide, offering lower rates of surgical site infection, reduced postoperative ileus and pain, faster recovery, and improved cosmesis [5]. Its dependence on advanced, costly technology, however, has constrained adoption in LMICs, where successful implementation requires both appropriate equipment and trained expertise [4]. Simulation-based training is the established route to that expertise: the FLS program is validated to improve and to predict intraoperative laparoscopic performance, and preparation to proficiency translates into better operative skill and greater intraoperative autonomy [7, 11–13]. More broadly, simulation paired with deliberate practice consistently outperforms traditional apprenticeship learning for procedural skills [14, 15]. Our findings extend this literature into a fully locally delivered program and reproduce its central promise: structured, feedback-rich practice produces large, measurable skill gains.

The feasibility of such programs in resource-limited settings has often been questioned on the grounds of cost and infrastructure. A successful laparoscopic skills curriculum depends on participant motivation, available resources and personnel, and faculty commitment [16]. In a 2009 survey, only 55% of 162 United States surgical training programs maintained a skills laboratory, with set-up costs ranging from roughly US$300 to US$1 million, and only 73% offered supervised training to residents [16]; in LMICs, such laboratories remain largely a privilege of large urban hospitals [5]. Yet the duration and resource intensity of training are not the principal determinants of benefit: interventions ranging from a single day to three years have yielded statistically significant outcomes across LMIC settings [17]. Our brief, intensive curriculum is consistent with this evidence, achieving large effects without the elaborate infrastructure of a high-income skills laboratory and, critically, using trainers that can be fabricated locally.

Our findings align with and build upon prior Ethiopian and LMIC experience. Earlier laparoscopic simulation courses for Ethiopian residents demonstrated feasibility and skill gains [8], and brief educational interventions have improved surgeons' knowledge in the same context [18]. Telesimulation and remote FLS coaching have produced meaningful skill acquisition in resource-restricted countries, underscoring that effective laparoscopic instruction need not be tethered to high-resource environments [19, 20]. We credit these foundational efforts; our contribution is to show that an entire blended curriculum, encompassing both didactic delivery and supervised hands-on instruction, can be designed, taught, and assessed locally and can succeed using simulators built in the country. In this respect, our program differs from the visiting-faculty or short-mission

model that has characterized much LMIC laparoscopic training, in which expertise is imported, and continuity depends on external teams.

The attenuation of the knowledge–skill association after training is an instructive observation and merits cautious interpretation. At baseline, participants approaching unfamiliar tasks drew on whatever conceptual understanding they possessed, so those with stronger theoretical knowledge performed better, with knowledge explaining roughly a quarter of the variance in initial skill. After concentrated deliberate practice, technical performance was no longer significantly associated with theoretical knowledge. This pattern is consistent with what skill-acquisition theory predicts: psychomotor laparoscopic competence is procedural and is built through repetition, feedback, and progressive refinement rather than through declarative knowledge [15, 21]. Once every learner received sufficient structured practice, the early advantage conferred by prior knowledge appears to attenuate, and hands-on experience emerges as the dominant correlator of performance. Because this inference rests on a comparison of two separate correlations rather than on a formal test of change in the association over time, it remains exploratory. The subgroup profiles cohere with this account: surgeons, with broader operative experience to scaffold new theory, advanced in both domains, whereas residents, whose principal deficit was procedural rather than conceptual, made their largest gains in skill. The observation that laparoscopy-naive surgeons can acquire suturing skills comparable to laparoscopy-exposed peers after training reinforces the same principle, that practice can overcome differences in prior exposure [22]. The practical implication is empowering: limited theoretical preparation should not bar enrollment, because supervised, deliberate-practice time, not prior knowledge, is the rate-limiting input for building laparoscopic skills.

Beyond the individual learner, the defining feature of this program was that it was locally owned. The curriculum was conceived, delivered, and assessed by in-country surgeons and succeeded with low-cost, locally fabricated trainers used alongside a small number of commercially available devices. This directly addresses the dependency that has limited many LMIC initiatives, in which capacity evaporates when visiting teams depart [4, 6]. A locally led model is inherently more sustainable: it builds a domestic faculty base, embeds training within existing institutions, and can be repeated and scaled on local terms. Because all participants trained on both platforms, the present study cannot establish the independent effectiveness of locally fabricated trainers or their equivalence to commercially validated devices; what it does show is that a curriculum built largely around locally fabricated trainers, supplemented by only three imported units, produced large skill gains. This is consequential because equipment cost and supply are among the most frequently cited barriers to laparoscopic training in LMICs [4, 5]; when effective trainers can be built within the country, the principal remaining input becomes faculty time, which a local-champion model is explicitly designed to generate. These findings align with the broader reorientation of global surgery away from a charitable, mission-based paradigm toward partnership, local ownership, and deliberate workforce development [1, 23], and they provide a concrete, replicable template for that shift.

Several limitations should be weighed against these strengths, which include the use of multiple complementary validated assessments, large and internally consistent effects across distinct outcomes, and non-parametric corroboration of the GRS finding. First, the single-group pre–post design without a control arm limits causal inference; we mitigated this by using each participant as their own control and by anchoring conclusions in objective timed metrics alongside the GRS rather than a single instrument. Second, outcomes were assessed on simulators immediately after training, so transfer to the operating room and skill retention were not measured; however, the FLS metrics employed are validated proxies that predict intraoperative performance [7, 13], and delayed reassessment is planned. Third, the sample was modest and drawn from a single national context, and two enrolled participants did not complete the paired skill assessment; reporting standardized effect sizes is intended to aid comparison and future pooling despite the sample size. Fourth, immediate knowledge gains were limited, particularly among residents, plausibly reflecting a ceiling effect given relatively high baseline scores on the 20-item instrument; a more discriminating knowledge test may be warranted in future iterations. Fifth, because all participants trained on both locally fabricated and commercially available trainers, and because practice time and repetitions on each platform were neither standardized nor recorded separately, the study cannot compare the two platforms or attribute the observed gains to either one. Sixth, post-training performance remained short of established FLS proficiency benchmarks, so the study demonstrates improvement rather than attainment of a defined competency standard. Seventh, analyses of individual categorical task elements and comparisons between surgeons and residents were not specified a priori, were not powered, and were not corrected for multiplicity; they are exploratory and hypothesis-generating, and the formal between-group comparison of change scores showed no significant difference by professional role. Finally, assessments were conducted within the program; although scoring was standardized and blinded, an independent rating would further reduce the potential for assessment bias.

Building on this work, future efforts should quantify skill retention through delayed reassessment, measure transfer to intraoperative performance and patient outcomes, and test scalability across multiple Ethiopian and regional centers using a train-the-trainer strategy to expand the local faculty base, accompanied by formal cost analyses comparing locally fabricated and imported trainers. The implications for practice and policy are immediate. For surgical educators in low-resource settings, investment should prioritize protected, supervised, and deliberate practice time and inexpensive, locally fabricated simulators over costly imported equipment. Furthermore, programs can enroll participants regardless of prior theoretical background. For institutions and global-surgery funders, the most durable returns will come from investing in locally owned training infrastructure and domestic faculty rather than episodic external missions.

Conclusion

In conclusion, this brief, intensive, locally led simulation-based curriculum produced large and consistent improvements in the laparoscopic skills of Ethiopian surgeons and residents. Prior theoretical knowledge was associated with technical performance before training but not after it, an exploratory observation suggesting that deliberate hands-on practice may act as an equalizer across learners of differing theoretical backgrounds. Because the program was designed, delivered, and assessed entirely by in-country faculty and succeeded using simulators that can be fabricated locally, it offers a replicable and scalable template for building minimally invasive surgical capacity in low-resource settings. This curricular model advances the shift from dependency toward local ownership and sustainable workforce development across the Global South.

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Data availability The de-identified datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest Drs. Woldehana, Suga, Mikru, Fanta, Bekele, and Malore are founding members of MIS Africa, a registered nonprofit organization in Ethiopia dedicated to advancing access to and training in minimally invasive surgery in Ethiopia and across Africa; these are unpaid roles. The remaining authors have no relevant financial or non-financial interests to disclose.

Ethical approval The study was approved by the Johns Hopkins University School of Medicine Institutional Review Board (IRB00442182). The host institution, Myungsung Medical College/MCM Comprehensive Specialized Hospital, determined that no additional local ethical approval was required.

Consent to participate Informed consent was obtained from all individual participants included in the study.

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