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Remote training in laparoscopy: a randomized trial comparing home-based self-regulated training to centralized instructor-regulated training

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Abstract

Background Simulation-based surgical training (SBST) is key to securing future surgical expertise. Proficiency-based training (PBT) in laparoscopy has shown promising results on skills transfer. However, time constraints and limited possibilities for distributed training constitute barriers to effective PBT. Home-based training may provide a solution to these barriers and may be a feasible alternative to centralized training in times of assembly constraints.

Methods We randomly assigned first-year trainees in abdominal surgery, gynecology, and urology to either centralized instructor-regulated training (CIRT) or home-based self-regulated training (HSRT) in laparoscopy. All participants trained on portable box trainers providing feedback on metrics and possibility for video reviewing. Training in both groups was structured as PBT with graded proficiency exercises adopted from the Fundamentals of Laparoscopic Surgery (FLS). The HSRT group trained at home guided by online learning materials, while the CIRT group attended two training sessions in the simulation center with feedback from experienced instructors. Performance tests consisted of hand–eye and bimanual coordination, suture and knot-tying, and FLS exercises. We analyzed passing rates, training time and distribution, and test performances.

Results Passing rates were 87% and 96% in the CIRT and HSRT group, respectively. HSRT facilitated distributed training and resulted in greater variation in training times. Task times for hand–eye and bimanual coordination were significantly reduced between pretest and posttest in both groups. Trainees maintained their posttest performances at the 6-month retention test. Our analyses revealed no significant inter-group differences in performances at pretest, posttest, or retention test. Performance improvements in the two groups followed similar patterns.

Conclusion CIRT and HSRT in laparoscopy result in comparable performance improvements. HSRT in laparoscopy is a feasible and effective alternative to CIRT when offered inside a supportive instructional design. Further research is needed to clarify trainees' preferences and explore facilitators and barriers to HSRT.

Keywords Surgery · Laparoscopy · Simulation · Remote learning · Proficiency-based training · Self-regulated learning

The rapid development of new surgical treatments and technologies, the growing demand for surgical expertise, the restrictions in work-hours, and the warranted focus on patient-safety continuously stress the need for surgical

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training outside the operating room (OR) [1–4]. Consequently, many countries have implemented simulation-based surgical training (SBST) in their postgraduate surgical training curricula. However, despite the benefits of SBST, it involves many resources and expenses for healthcare systems: simulation facilities, equipment, staff, instructors, participants, etc. Research is needed to explore SBST designs that address these challenges. We propose that accessible, flexible, and individualized SBST programs consistent with trainees' concurrent clinical training opportunities may opt for a solution to some of these challenges.

Laparoscopic surgery is technically challenging due to the limited visibility, the 'fulcrum effect', the diminished haptic feedback, and the distorted visuospatial input. Research has shown that proficiency-based training (PBT) in laparoscopy results in performance improvements that are transferred to the OR and results in fewer surgical complications [5–10]. PBT is a goal-oriented approach to SBST, where performances rather than training time and number of repetitions determine participants' progression through the training program. PBT aims to bring trainees to uniform levels of performance while accommodating the ability and development of the individual. However, PBT can be more time-consuming and require more repetitions compared to traditional interval training. Accordingly, simple and readily available systems for SBST have been developed, and studies have demonstrated that laparoscopic psychomotor skills can be effectively trained and acquired using basic, inexpensive, and low-fidelity box training models (BTs) [11–13]. Portable BTs allow trainees to engage in training at home at their own discretion outside simulation facilities' opening hours [14, 15]. In addition, it allows for more distributed training, which has proven effective in developing and retaining laparoscopic skills [16, 17]. Opportunities for centralized training are challenged by trainees' geographical distribution, work-hour restrictions, accessibility of simulation facilities, and recruitment of instructors. Surgical training at home can help overcome some of these barriers and may support transfer of training by enabling timely coherence between SBST and concurrent apprenticeship training in the OR [18, 19]. Also, centralized face-to-face teaching has recently been disrupted by the COVID-19 pandemic, requiring a rapid transition to remote learning and necessitating home-based learning activities [20].

Previous studies explored autonomous approaches to home-based training in laparoscopy and found large variations in trainees' compliance with training [21, 22]. Accordingly, it has been emphasized that curricular requirements, goal setting, testing, and protected training time, i.e., training time incorporated into working-time, protected from clinical responsibilities [21], are essential factors for assuring trainees' commitment to training [22–24]. Studies of training programs with proficiency goals and pass/fail criteria found that access to independent home-based training resulted in comparable performance improvements and increased training distribution compared to control groups with access to independent training in simulation centers [25–27]. Unlike previous studies, the present study does not investigate independent training, but compares centralized instructor-led training to structured and supported home-based training in laparoscopy. Current literature reports ambiguous results of the instructor's direct and indirect role and the value of concurrent instructor feedback during surgical training [28–35]. However, research comparing centralized instructor-regulated training to self-regulated home-based training in laparoscopic skills is scarce. Consequently, the aim of this study was to compare training in two different learning environments and with two different instructional approaches.

Self-regulated learning (SRL) has been explored as a relevant approach in medical education and simulation-based training [36]. A key assumption in SRL is that goal setting stimulates self-regulation in learning [37]. SRL involves a cyclical process through which trainees modulate affective, cognitive, and behavioral processes and thereby adapt their learning strategies to reach desired goals [38, 39]. However, SRL should not be framed as an individualistic activity. A systematic review of SRL in simulation-based training advocates that SRL is not merely self-learning but self-regulated learning using designed educational supports [40]. Previous comparisons of instructor-regulated learning and directed SRL in simulation-based training indicate the benefits of SRL and emphasize that trainees need evidence-based educational supports for SRL [40–42]. Goal lists, video instructions, video reviews, and computer-generated feedback have proven effective as educational supports for SBST [30, 32, 40, 43–45]. To date, we are not aware of studies that applied all of these educational supports in a home-based PBT program in laparoscopy.

A comparison that considers the instructor's influence in the centralized training setting is warranted. Consequently, we aimed to compare the respective impacts of centralized instructor-regulated training (CIRT) and home-based self-regulated training (HSRT) on acquiring and retaining basic laparoscopic psychomotor skills.

Materials and methods

The study design was a prospective, randomized comparative trial with two parallel arms. The study was approved by the Regional Ethics Committee (no. 1-10-72-233-18) and the Institutional Review Board at Aarhus University (no. 2019-0006645). The research project is registered at Aarhus University under the General Data Protection Regulation (no. 2016-051-000001). The study is registered at ClinicalTrials.gov (no. NCT04401306).

Setting and participants

The study was conducted at Aarhus University, Denmark, in collaboration with the simulation centers in Central and Northern Denmark Region (MidtSim and NordSim). We enrolled first-year trainees in abdominal surgery, gynecology, and urology within Central and Northern Denmark Region between March 2019 and March 2020. First-year trainees who had not previously participated in a simulation-based laparoscopic training program during their first-year training were eligible for inclusion. Trainees who had performed more than 50 supervised laparoscopic procedures were excluded from the study. Based on previous employment rates, we predicted the number of eligible first-year trainees employed in the two regions within the 1-year enrollment period to be 42–50. The training program was planned and coordinated in a working group consisting of the authors, representatives from the simulation centers, and laparoscopic experts within the three specialties involved. We randomly allocated participants to either CIRT or HSRT in basic laparoscopic skills. All trainees volunteered for the study and provided informed consent.

Randomization and allocation

We enrolled participants continuously in groups of 6–10 and randomly allocated them to the CIRT or the HSRT group. We used non-stratified block randomization with block sizes randomly varying between two and four, aiming at an allocation ratio of 1:1. The randomization was performed using an investigator-hidden allocation sequence prepared by a non-affiliated data manager.

Training equipment

All participants trained on the validated eoSim portable box trainer (eoSurgical, Edinburgh, Scotland) (Fig. 1) [46, 47]. The setup consists of a portable laparoscopic case with an internal camera and a light source connected to a computer via USB. Trainees used the software SurgTrac (eoSurgical, Edinburgh, Scotland) to access video instructions for exercises of varying difficulty. SurgTrac provides basic feedback on instrument metrics and allows the participant to review previous exercises, which can help guide future training efforts. Data on training exercises and training time (time the camera in the box was turned on) were stored in the system. eoSim and SurgTrac is compatible with the exercises from the Fundamentals of Laparoscopic Surgery (FLS) training program and includes a grading system for all exercises.

Fig. 1 The eoSim portable box trainer (eoSurgical, Edinburgh, Scotland) used for training in both study arms

Study and training design

An overview of the study and training design is shown in Fig. 2. Training in both groups was structured as PBT with validated proficiency exercises adapted from the FLS training program [48, 49]. The working group agreed that the basic laparoscopic training program should provide first-year trainees with the basic psychomotor skills necessary to progress in their laparoscopic training in the simulated environment and the OR. Thus, it was decided that the training program should contain two modules with two primary learning objectives: Module (1) Psychomotor and visuospatial skills, and Module (2) Suture- and knot-tying skills. Accordingly, the FLS exercises 'peg transfer' and 'suture with intracorporeal knot' were used as proficiency tasks. Based on experiences from a pilot study, exploring the training possibilities within the 6-week time-frame, it was not feasible to apply the same proficiency levels for the two tasks as defined in the FLS program. Hence, we set the proficiency levels in accordance with the established grading system in SurgTrac, with a minimum passing standard for each task corresponding to grade B. Participants were given clear instructions on performance goals and proficiency levels for the tasks. To reach proficiency in Module (1), and obtain a grade B (acceptable) or a grade A (excellent), participants needed to perform the 'peg transfer' exercise correctly in less than 100 s or 48 s, respectively, demonstrated in three consecutive repetitions. To reach proficiency in Module (2), and obtain a grade B or grade A, participants needed to perform the exercise 'suture with intracorporeal knot' correctly in less than 240 s or 140 s, respectively, demonstrated in three consecutive repetitions.

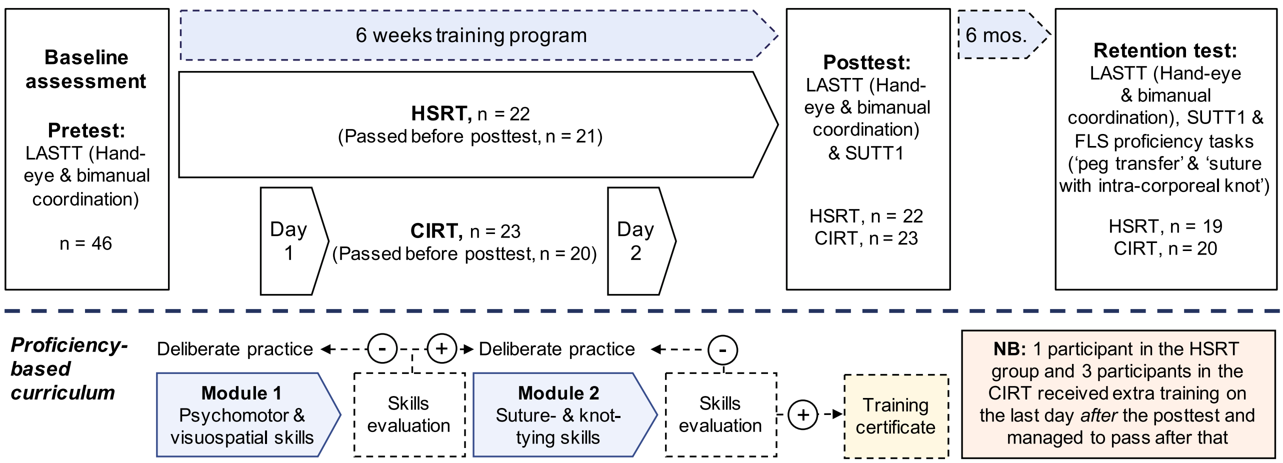

Fig. 2 Study and training design. *CIRT* centralized instructor-regulated training; *HSRT* home-based self-regulated training

Participants submitted their video-recorded performances for evaluation via SurgTrac. Whenever trainees submitted a video that did not live up to the proficiency criteria, corrective feedback was given in short written format. According to the pass/fail criteria, participants had to demonstrate proficiency in both exercises before meeting on the last day of the 6-week training program where posttests were performed. Due to ethical reasons and the dual purpose of being a training program and a scientific study, trainees who did not pass the training program within the study period ($n = 4$) were allowed extra instructor-guided catch-up training after the posttest on the last day. All trainees were tested and analyzed following the intention-to-treat principles. After passing the training program, trainees received certificates stating the grades for each of the two modules, and they were approved to sign up for more advanced laparoscopic training on anesthetized pigs.

Training interventions

The CIRT group attended two 7-h training days in the simulation center situated in weeks three and five of the training program. The training was scheduled during normal working hours, and trainees were protected from clinical responsibilities (protected training time) and paid by their clinical departments while participating. The training was guided by experienced instructors and laparoscopic experts within the three specialties. We kept a minimum ratio of instructors to trainees of 1:3 during all training sessions in accordance with recommendations from Dubrowski and MacRae [50]. Instructors could give feedback and advice on their own and the trainees' requests on any aspect of the trainees' performance. Instructors were encouraged to allow trainees to engage in deliberate practice without interruptions when warranted. The training days in the CIRT group included a 30-min lunch break and a 15-min coffee break. Otherwise, the trainees could train as they wished, but were encouraged to take breaks from training as needed.

The trainees in the HSRT group brought the portable box trainer home during the 6-week training program. They were given two paid working days without clinical responsibilities to ensure equivalent protected training time as the CIRT group. However, in contrast to the CIRT group, trainees in the HSRT group had the freedom to structure and distribute their training as they wished, independent of their scheduled days with protected training time. They had access to online video instructions on the proficiency tasks and thorough instructional videos focusing on process goals in the training of intracorporeal suture and knot-tying. Information, instructions, and process goals were also distributed in writing.

Baseline assessment and pretests

All participants met in the simulation center on the first day of the study, where they were given information on the study and instructions on the training program and equipment. The first day included lectures on PBT and basic principles of laparoscopy. All participants answered a baseline questionnaire where demographics, handedness, and previous laparoscopic and gaming experience was assessed. Participants' previous laparoscopic experience was categorized as low or moderate (high experience was incompatible with the inclusion criteria). Previous gaming experience was categorized as low, moderate, or high (Table 1). Participants were assigned to the different experience categories based on their responses to the baseline questionnaire (see table legend). The scoring system and the corresponding categories were defined by consensus in the author group. Participants' visuospatial skills were assessed using a previously

Table 1 Demographics and previous experience

	CIRT ($n=24$)	HSRT ($n=22$)	p value
Sex (male/female), n	9/15	5/17	0.27
Age, median (range)	30 (27–36)	30 (26–36)	0.87
Post graduate years, median (range)	2 (1–13)	2 (1–7)	0.96
Specialty (surgery/gynecology/urology), n	13/7/4	11/6/5	0.87
Handedness (right/left/mixed), n	21/2/1	18/1/3	0.47
Laparoscopic experience[a] (low/moderate), n	20/4	17/5	0.61
Gaming experience[b] (low/moderate/high), n	18/4/2	19/2/1	0.62

CIRT centralized instructor-regulated training, *HSRT* home-based self-regulated training

[a]Based on score calculated from previous number of laparoscopic procedures under supervision (0, > 0, > 10, > 20, > 30; 0–4 points), as an assistant (0, > 10, > 30; 0–2 points), and previous laparoscopic training (no/yes; 0/1 points). Score 0–3 = "low", score > 3 = "moderate"

[b]Based on score calculated from previous gaming (no/yes; 0/1 point), time of regular gaming (> 5 years ago, within last 5 years, within last year, within last 3 months.; 0–3 point), hours spent gaming per week (< 1, 1–5, 6–10, > 10; 0–3 points). Score 0–2 = "low", score 3–5 = "moderate", score > 5 = "high"

validated mental rotation test (MRT) with a maximum score of 24 [51].

We conducted the laparoscopic skills tests on the Szabo pelvic trainer box using a real all-in-one laparoscopic tower setup (Karl Storz, Tuttlingen, Germany). Participants were tested in pairs with a research assistant present to give instructions and time the tests. Participants changed places between each repetition alternating between being tested and being observer/camera-assistant of the tested. Research assistants were unaware of participants' training allocation.

Participants' baseline laparoscopic psychomotor skills were assessed using the laparoscopic skills testing and training (LASTT) model developed and validated by Molinas et al. [52]. We tested the participants' hand–eye coordination and bimanual coordination. The hand–eye coordination task tests the participant's ability to coordinate the visual input from a 0° optics in the non-dominant hand with the movements of a laparoscopic forceps in the dominant hand, transporting six colored beads onto six target pegs at different locations in the LASTT model. Bimanual coordination tests the participant's ability to coordinate two laparoscopic forceps simultaneously when transporting six colored push pins onto six different locations in the LASTT model.

Outcomes measures

The LASTT hand–eye and bimanual coordination tests were performed at baseline (pretest), after the training program (posttest) and at a 6-month follow-up (retention test) (Figs. 2 and 3). For both LASTT tests, a maximum of 180 s was allowed in each attempt. Participants were tested in three repetitions of each task. The outcome measures of the tests were the time to finish all objectives of the tasks correctly. If participants did not finalize the tasks or if they dropped the colored objects out of reach, the maximum time was registered for that repetition. In the latter case, participants received one additional attempt, and the average time of four trials was calculated. The average time of the three or four repetitions was used for statistical analysis. Lower completion times reflect better performance. The tests have been described in more detail in previous validation studies [52, 53].

The suturing and knot-tying training and testing (SUTT1) model developed by the European Academy of Gynecological Surgery [54] was used for testing participants suturing skills at posttest and retention test. SUTT1 tests the participant's ability to perform five stitches and one intracorporeal knot through a foam pad in a maximum of 900 s. Test scores were based on four quality indicators: the number of dots through which the thread was passed correctly (0–10 points), the number of correct stitches (0–5 points), the presence of a correct and tied knot (0/2 points), and the degree of trauma (negative 0–2 points). If the participants completed the task before the maximum 900 s and at the same time managed to make a correct and tied knot, an extra point was added to the score. This resulted in overall scores ranging from − 2 to 18, where higher scores reflect better performance. Two outcome assessors who were blinded to the participants' training allocation and timing of the tests (post/retention) independently scored the tests by assessing the SUTT1 foam pads.

In addition, we also tested the participants' ability to perform the FLS proficiency exercises at the retention test, giving them one attempt to perform each exercise on the portable box trainer. The performance measure in the 'peg transfer' task was the completion time, with lower completion times reflecting better performance. For the FLS exercise 'suture with intracorporeal knot', we used a previously published scoring formula where higher scores reflect better performance: 600 − time (s) − (penalties × 10) [55]. If participants failed to complete an intracorporeal knot within the time limit (10 min), a score of zero was given.

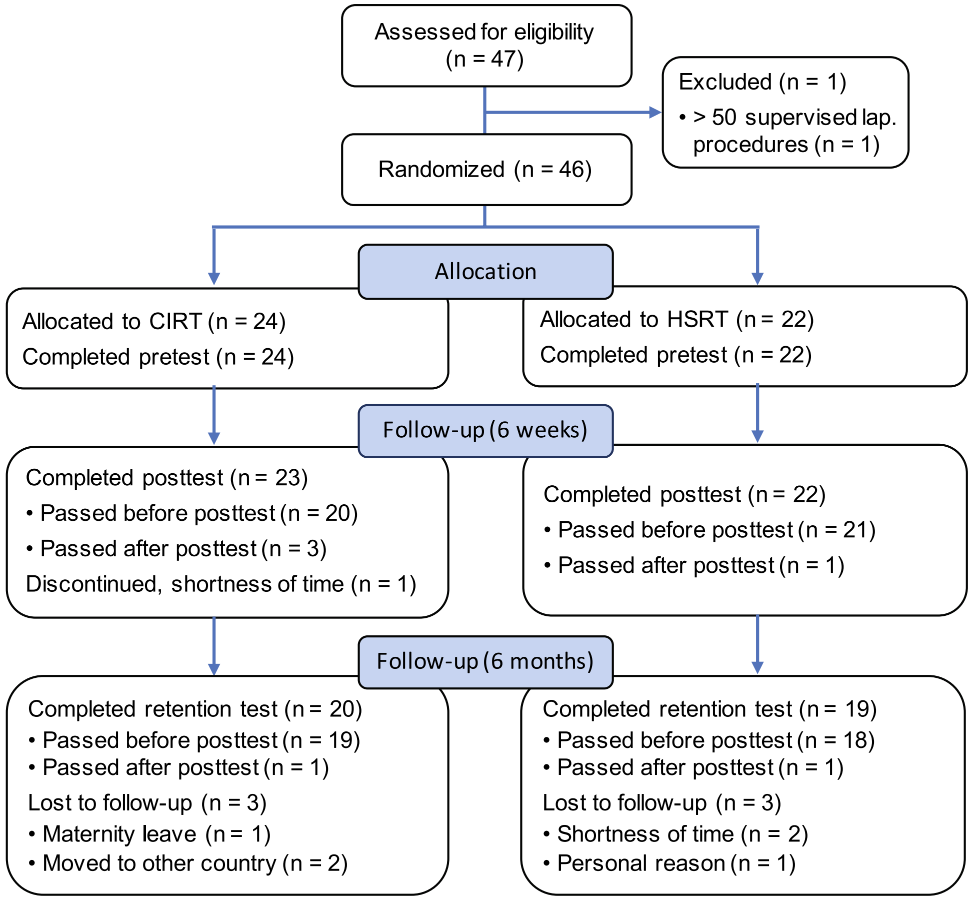

Fig. 3 Participant flowchart. *CIRT* centralized instructor-regulated training; *HSRT* home-based self-regulated training

The total training time and training variation (number of different exercises trained) of each participant were calculated, excluding training data from the last day of testing and catch-up training. Similarly, the total training time for participants to pass the training program (reach proficiency in both modules) was calculated, excluding the participants that did not manage to pass before the posttest ($n = 4$). For assessing training distribution, we calculated days with training.

Data analyses and statistics

Demographics, baseline data, passing rates, module grades, and training times and variation between the two groups were evaluated and compared using a likelihood ratio chi-square test for categorical variables and a linear regression model for continuous variables. Comparisons of training times were made using the log-transformed data. Test performances for LASTT (hand–eye coordination and bimanual coordination) and SUTT1 tests were analyzed and compared using a mixed model for repeated measurements with group and time and their interaction as fixed effects and participants as random effect. The interaction between the group and time were tested using likelihood ratio test. The changes in performance from pretest to posttest within and between the groups were compared using the contrasts following the mixed model. The mixed model also allowed us to analyze performance results at retention test, adjusting for the self-reported number of laparoscopic procedures participants had performed and assisted during the 6-month retention period. FLS retention test results were compared using a linear regression model using log-transformed data for the ‘suture with intracorporeal knot’ task scores. Inter-rater reliability on the SUTT1 assessments was calculated using the intraclass correlation coefficient (ICC) under a mixed model setup. A p value < 0.05 was considered significant. Data on training variation and training distribution are presented in means ± standard deviations. Data on training times are presented in medians with interquartile ranges (IQR). Data on test performances are presented as marginal means or medians (if analyzed using log-transformed data) with corresponding 95% confidence intervals (CI). Data were analyzed using STATA ver. 16.1 (StataCorp. 2019. College Station, TX, USA).

Results

As shown in Fig. 3, 46 participants were randomized to either CIRT or HSRT and tested at baseline (pretest). One participant in the CIRT group discontinued after the pretest due to shortness of time. We collected posttest data for 45 participants and 6-month retention test data for 39 participants. Three participants in the CIRT group and one participant in the HSRT group failed to pass before the posttest. However, all of these participants managed to pass with further catch-up training after the posttest on the last day. The calculated ICC (0.95) indicated excellent reliability in SUTT1 scores between the two blinded assessors. Accordingly, we used the average of the SUTT1 scores between assessors in our further statistical analyses. Demographics and previous laparoscopic and gaming experience were comparable in both groups (Table 1). We found no significant differences in visuospatial ability at baseline (mean MRT scores: 11 vs. 10; $p = 0.82$).

Training patterns, passing rates, and module grades

There were no significant differences in median total training times (368 vs. 330 min; $p = 0.89$), total training time to pass (373 vs. 312 min; $p = 0.39$), or mean training variation (6 vs. 6 different exercises; $p = 0.86$) between the two groups (Table 2). While the participants in CIRT group could only train on the two scheduled days, the participants in the HSRT group, on average, distributed their training over 7 ± 3 days. The trainees in the HSRT group distributed their training over the 6-week period with a peak in median training time on day 24 (Fig. 4). 28% of the training sessions were on days where the participants in the HSRT group were off from their clinical work (days with protected training time).

Although we found no significant differences between the CIRT and the HSRT group in the proportions of participants who passed before the posttest (87% vs. 95%; $p = 0.31$) or achieved grade A in Module (1) (9% vs. 18%; $p = 0.35$) or Module (2) (17% vs. 27%; $p = 0.48$), respectively, we saw that the percentages tended to be in favor of HSRT. Based on

Table 2 Training measures

	CIRT	HSRT	*p* value
Total training time (min), median (IQR)	368 (320–413)	330 (248–415)	0.89
Total training time to pass[a] (min), median (IQR)	373 (334–411)	312 (248–415)	0.39
Days with training (*n*), mean ± SD	2 ± 0	7 ± 3	< 0.001
Training variation (*n*), mean ± SD	6 ± 1	6 ± 2	0.86

CIRT centralized instructor-regulated training, *HSRT* home-based self-regulated training

[a]Includes data on participants that managed to pass (reach proficiency in both modules) before the posttest (CIRT: $n = 20$, HSRT: $n = 21$)

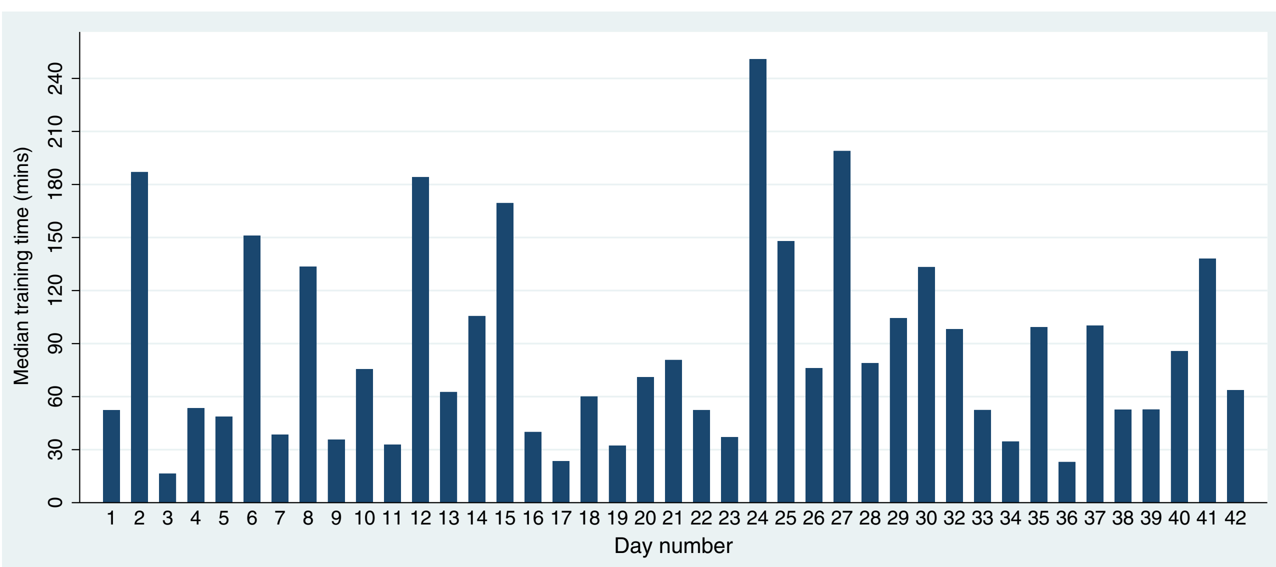

Fig. 4 Median training time and distribution in the home-based self-regulated training (HSRT) group. The *y*-axis shows the median training time in minutes, and the *x*-axis shows the day number in the 6-week training program (42 days)

the available data, we estimated that approximately 700 participants would be needed to have a 90% chance of detecting a difference significant at the 5% level, which was not feasible in our setting.

Test performance data

Analyses using the mixed model for repeated measurements demonstrated that both groups improved significantly in their performances from pretest to posttest. For hand–eye coordination, the estimated decrease in mean task time was 33 (95% CI 18–48; $p < 0.001$) and 46 (95% CI 31–62; $p < 0.001$) seconds in the CIRT and HSRT group, respectively. For bimanual coordination, the estimated decrease in mean task time was 24 (95% CI 15–34; $p < 0.001$) and 24 (95% CI 14–34; $p < 0.001$) seconds in the CIRT and HSRT group, respectively. For the SUTT1 posttest, the estimated mean score was 8.5 (95% CI 6.7–10.3) and 8.7 (95% CI 6.8–10.5) in the CIRT and HSRT group, respectively.

Using the statistical model to compare retention test with pretest performances, we found that task times for the hand–eye and bimanual coordination tests remained significantly decreased after 6 months in both groups (p values < 0.001). Our analyses revealed no significant changes in SUTT1 scores when comparing results from the retention test to results from the posttest (p values > 0.05). Task times for bimanual coordination were further significantly decreased from posttest to retention test in both groups (p values < 0.05). For the FLS retention test results, our analyses revealed mean task times of 106 (95% CI 95–117) and 104 (95% CI 93–115) seconds for the 'peg transfer' task and median scores of 331 (95% CI 282–389) and 313 (95% CI 266–367) for the 'suture with intracorporeal knot' task in the CIRT and HSRT group, respectively.

Our analyses revealed no significant inter-group differences in any of the performance measures at pretest, posttest, or retention test, respectively (p values > 0.05). In addition, we found no evidence of group-test interactions, indicating that there were no significant differences in the performance developments in the two groups between the three tests in time (Fig. 5).

Further analyses, adjusting for self-reported clinical laparoscopic activity during the 6-month retention period, did not change the results significantly.

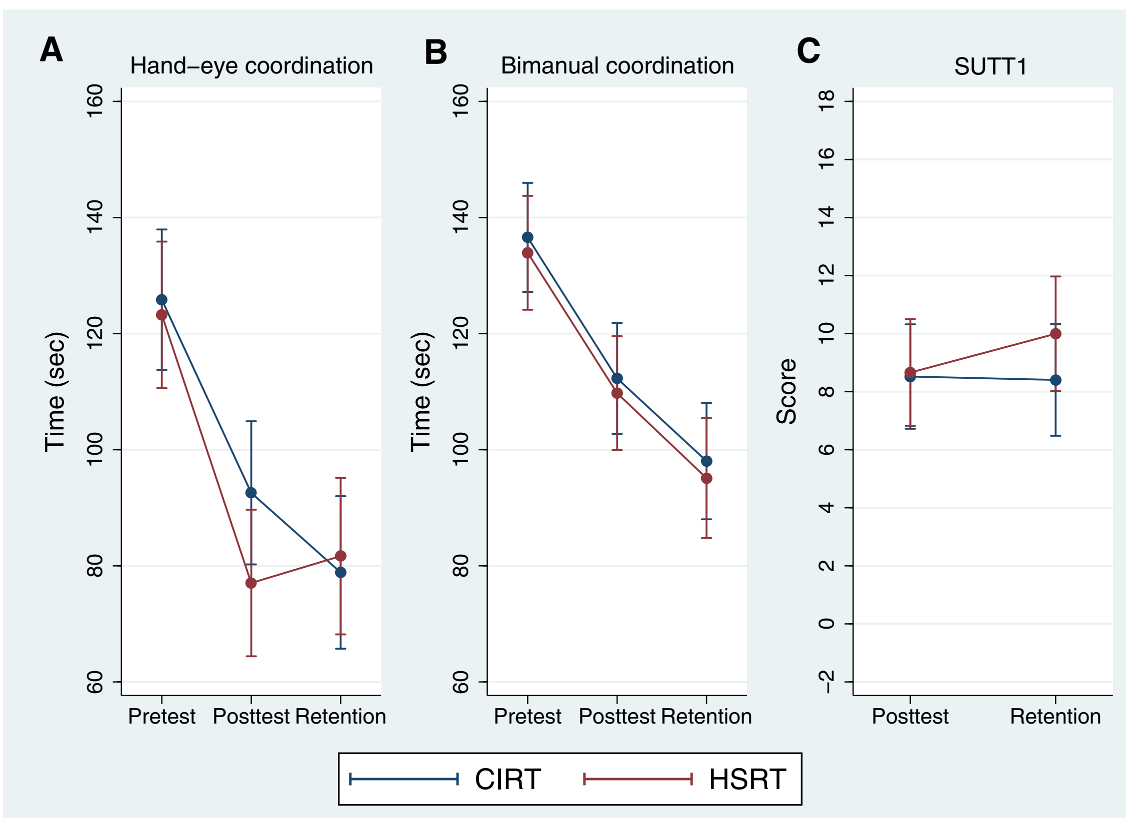

Fig. 5 Task times for the LASTT hand–eye (**A**) and bimanual (**B**) coordination tests at pretest, posttest, and retention test. SUTT1 scores (**C**) at posttest and retention test. Data points indicate marginal means and whiskers the corresponding 95% confidence intervals. *CIRT* centralized instructor-regulated training; *HSRT* home-based self-regulated training

Discussion

To the authors' knowledge, this is the first randomized trial comparing CIRT to HSRT in basic laparoscopic psychomotor skills for first-year trainees in abdominal surgery, gynecology, and urology. To demonstrate each intervention's training effects, we have presented data on training patterns and performance outcomes. We found similar total training times between the two groups, which is interesting considering that the HSRT group had the training equipment throughout the 6-week period and thus had the opportunity to train more than the CIRT group. We believe that this finding underpins the importance of protected training time and PBT. This interpretation may seem contradictory to our findings that trainees in the HSRT did not primarily engage in training on the days scheduled for protected training time. They distributed their training sessions as they felt appropriate. However, we argue that the provision of protected training time helps to recognize the importance of training, and gives trainees incentives to train and a sense of support, which together with PBT helps to drive their motivation. While this type of support is important in the early stages of surgical training [21], we also believe that surgical trainees need to develop motivation and strategies to continuously practice and maintain their skills and competencies independently during their professional development. That being said, the question of how to support the development of such motivation and strategies is beyond the scope of this paper.

Our results demonstrate that training times in the HSRT varied more than in the CIRT group. In accordance with previous studies, we believe that home-based training led trainees to take a more individualized approach to training [24]. First-year trainees from three different specialties bring different prerequisites and experiences into a training program, and therefore it is expected that some trainees require more training time than others before reaching proficiency. As such, we assume that HSRT allow trainees to progress more independently along their individual learning curves, which may result in a more appropriate and efficient training process. However, further exploratory studies are needed to substantiate this assumption.

We found immediate performance improvements in hand–eye and bimanual coordination skills after training in both groups. And these performance improvements were retained at the 6-month retention test. For suturing and knot-tying skills, we found that trainees in both groups scored relatively low in the SUTT1 test, consistently at posttest and retention test. By contrast, we found that participants attained scores comparable to trained surgeons and senior residents in the FLS retention test performing the 'suture with intracorporeal knot' task [48]. These findings indicate that the skills acquired through training the FLS exercise 'suture with intracorporeal knot' are not easily transferred to the more complex task of stitching and knot-tying as described in the SUTT1 test.

Inter-group comparisons revealed comparable results with consistently overlapping confidence intervals for all performance measures. Furthermore, trainees developed their skills similarly between pre-, post-, and retention tests in the two groups. Performance levels were equally retained at the 6-month retention test in both groups. These findings collectively indicate that HSRT is effective and comparable to CIRT in terms of acquisition and retention of basic laparoscopic skills and in terms of training engagement and variation. Consistent with previous studies, we found that home-based training facilitates distributed training [25, 27]. By contrast, we found no indication that trainees tended to mass their training towards the end of the training period [24].

Interestingly, we found that trainees' bimanual coordination skills were further improved from posttest to retention test in both groups, even when adjusting for interim laparoscopic activity. This result indicates that bimanual coordination skills that are transferable to laparoscopy are also acquired through other clinical activities than merely laparoscopic surgery.

The study was inspired by previous research exploring the effects of applying the educational theories of SRL in simulation-based training. We based our study on recommendations for further research in this field [23, 40]. Allowing trainees to organize their own training requires them to take an active part in their learning processes and training strategies. Supportive instructional designs are essential to this approach, especially for early learners, emphasized in the emerging SRL approach called directed self-regulated learning [36, 41, 56]. In this context, the term 'scaffolding' has previously been used as a metaphor to describe the type of support that teachers and instructional designers offer to support learning [57]. Scaffolding is conceptualized as the process of providing temporary support structures that enable a learner to carry out a task or achieve a goal that would be beyond the learner's capacity without the assisting scaffold. In other words, scaffolding helps the learning process from the current development level as determined by independent problem solving to what Vygotsky called *the zone of proximal development* as determined through problem solving under guidance or in collaboration with more capable peers [58]. In this way, scaffolding is a dynamic pedagogical tool based on a flexible, temporary, and 'teacher-regulated' structure of support, which is gradually dismantled as the learner progress towards independence and self-regulated learning [57].

In the present study, the scaffolding for HSRT was constructed from a proficiency-based training design with protected training time, instructional videos, process goals, computer-generated feedback, the possibility for self-evaluation, and short written feedback on submitted videos. In contrast to previous home-based training studies, we demonstrate that within this scaffolding, trainees engage in home-based training with commensurate commitment and comparable performance improvements as instructor-regulated trainees in the simulation center. Theories on self-regulated learning provide a conceptual framework for interpreting these findings. Goal setting triggers self-regulation [37]. However, extrinsic performance goals can sometimes have unfavorable effects on trainees' performances, which apparently contrasts with proficiency-based training [37]. Notably, SRL literature argues that process goals can operate as proximal regulators of distal performance goals and that the process of attaining goals can have an internalizing effect on trainees' motivation [38]. In the present study, trainees received process goals aimed at achieving proficiency in specific performance goals. According to Zimmerman [38], this approach would help stimulate trainees' motivation to train. External motivators were the differentiated grading of exercises, the rewarding of high-performers, and the requirement of proficiency for progression. Within the 'scaffolding', trainees in the HSRT group were given freedom and autonomy, which may have promoted their self-monitoring and self-evaluation of learning processes and progression in training. Consistent with a previous study by Brydges et al. [41], we presume that trainees in the CIRT group relied more on instructor-monitoring and peer-mirroring in their training. However, this presumption needs further exploration, which we plan to do in a future study.

Home-based surgical training programs have some obvious advantages in terms of reducing resources, overcoming structural barriers, and transitioning to remote learning in times of need. However, our study also demonstrates that the 'scaffolding' needs proper construction to optimize training outcomes. This requires time of instructional designers, participants and assessors, and resources for developing educational supports. We argue for another advantage of home-based training, namely the opportunity for timely transfer of training. In postgraduate surgical training, clinical opportunities for training in the OR are not always temporally consistent with possibilities for engaging in simulation-based training [59]. By providing surgical trainees with immediate accessible, and flexible training opportunities, they can structure their training to mirror concurrent training possibilities in their clinical rotations. Reducing delays in opportunities to perform optimizes transfer outcomes and may, in turn, increase trainees' perceived utility of training and motivation to train [18].

A number of study limitations should be noted. Firstly, the number of participants was limited to 46 within our enrollment period. The dual purpose of being a training program and a scientific study, and the limited opportunities for recruitment made further inclusion unfeasible. These limitations are common in postgraduate training studies and our sample size is reasonable compared to other studies in the field. Notably, we chose a comparative approach to contribute to the understanding of the impacts of two different training interventions, each of which constitutes complex learning environments where numbers and outcomes are guiding but not unambiguously determinant for the interpretation. Secondly, the HSRT group was not strictly home-based, as the participants in this group were present in the simulation center on the first day when the training equipment was demonstrated and theoretical lectures were held. However, no training was allowed on the first day, and we argue that lectures and demonstrations can easily be converted to remote learning activities. On the other hand, it could also be favorable to combine elements of CIRT and HSRT, and thereby reap the benefit of both approaches. Future research should examine how to best integrate CIRT with HSRT in SBST. Thirdly, we modified the training protocol and proficiency levels from the FLS program so that it was feasible to conduct the study within the framework of our training program. This may raise concerns about validity. However, in this context, it is important to notice that rather than using the FLS exercises in a determinant final test, we used them as grade-differentiated proficiency goals within the training program. Finally, we used a simulated model for testing participants. Our study demonstrates that hand–eye and bimanual coordination skills acquired on a basic portable box training model with a fixed camera transfer into improved performances on a test model using a real laparoscopic setup. However, demonstrating transfer of skills to the OR is always warranted. As such, this study relies on previous studies that have demonstrated that PBT in laparoscopy leads to improved skills in the OR [5–10]. The training and test models used in our study have proven to be valid and reliable in evaluating trainees' technical skills before they are allowed to perform laparoscopic procedures in the OR [10, 48, 60, 61].

Some readers may ask: Which training approach is superior to the other? However, this paper was not aimed at demonstrating the superiority of one training approach over the other. By contrast, we argue that it may be reductionist to conclude superiority based solely on outcome measures when comparing complex learning environments. As such, we strongly agree with the suggested shift in educational research from the imperative of proof to an imperative of understanding [62]. Our study contributes to understanding the differences and similarities between two distinct SBST approaches, adding to the evolving research in remote learning and SRL in medical education. From an organizational point of view, the study indicates that stakeholders in SBST have the opportunity to give trainees choice and flexibility in SBST, which may benefit quality, planning, and resource use in postgraduate surgical education. We recommend that future research examine mechanisms and preferences within the different learning environments and explore facilitators and barriers to home-based SBST.

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