Effects of Systematically Guided vs. Self-Directed Laparoscopic Box Training on Learning Performances: An Observational Study

Auswirkungen eines systematisch geführten laparoskopischen Boxtrainings verglichen mit selbstgeleitetem Training auf die Lernleistung: eine Beobachtungsstudie

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Keywords

laparoscopy, box training, learning performance, surgical education, structured training

Schlüsselwörter

Laparoskopie, Boxtraining, Lernleistung, chirurgische Ausbildung, strukturiertes Training

received 29.8.2024
accepted after revision 14.9.2024

Bibliography

Geburtsh Frauenheilk 2024; 84: 1135–1142
DOI 10.1055/a-2415-5929
ISSN 0016-5751

Georg Thieme Verlag KG, Rüdigerstraße 14, 70469 Stuttgart, Germany

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ABSTRACT

Introduction

Minimally invasive surgery is increasing in all fields of surgery. It is currently unknown whether structured training is superior to self-directed training. The aim of this study is to analyze the enhancement of surgical skills in laparoscopy box trainers in a systematically guided training program compared to self-directed training.

Material and Methods

Two groups of 40 medical students were included in the study between 04/2021 and 01/2023. Each training session on the laparoscopic box trainer (Medishield BV, NL) was automatically protocolled, including time, force, and path length. The structured group consisted of 21 students working in peer tandem, while the self-directed group consisted of 19 last-year students in their four-month elective. The observational study was conducted in an ecological study design.

Results

The self-directed cohort completed an average of 15 training sessions compared to the structured cohort's 10 sessions. All participants in both groups improved in time, path length, and force. The structured cohort showed nearly linear improvement, while the self-directed cohort had high deviation in results.

Conclusion

Supervision and collaborative work positively influence laparoscopic training success. Mere availability of training does not exploit the potential of laparoscopic box trainers. Curriculums for young surgeons or medical students should include institutionalized training with a structured schedule and a training partner for improved outcomes.

ZUSAMMENFASSUNG

Einleitung

Minimalinvasive Interventionen werden zunehmend in allen Gebieten der Chirurgie durchgeführt. Noch unbekannt ist aber, ob ein strukturiertes Training zu besseren Ergebnissen führt als ein selbstgeleitetes Training. Ziel der Studie war es, zu untersuchen, ob sich die chirurgischen Fähigkeiten nach einer Ausbildung am laparoskopischen Boxtrainer mit einem systematischen Trainingsprogramm im Vergleich zu einem selbstgeleiteten Training verbessern.

Material und Methoden

Zwischen 04/2021 und 01/2023 wurden insgesamt 40 Medizinstudenten und -studentinnen in die Studie aufgenommen und in 2 Gruppen unterteilt. Jede Trainingseinheit mit dem laparoskopischen Boxtrainer (Medishield BV, NL) wurde automatisch protokolliert, einschließlich der aufgewendeten Zeit, der Krafteinwirkung und der Weglänge. Die strukturierte Gruppe bestand aus 21 Studierenden, die im Tandem mit gleichrangigen Studierenden arbeiteten. Die selbstgeleitete Gruppe bestand aus 19 PJ-Studierenden in ihrem gynäkologischen Wahltertial. Die Beobachtungsstudie wurde als ökologische Studie konzipiert und durchgeführt.

Ergebnisse

Die selbstgeleitete Kohorte führte durchschnittlich 15 Trainingseinheiten durch verglichen mit den 10 Trainingseinheiten der strukturierten Kohorte. Bei allen Teilnehmern aus beiden Gruppen gab es Verbesserungen hinsichtlich der Zeit, der Weglänge und der Krafteinwirkung. Die Verbesserungen in der strukturierten Kohorte waren fast linear, wohingegen es große Schwankungen in den Ergebnissen der selbstgeleiteten Kohorte gab.

Schlussfolgerung

Training unter Aufsicht und kollaboratives Arbeiten haben positive Auswirkungen auf den Erfolg von laparoskopischem Training. Die Verfügbarkeit von Trainingsmöglichkeiten allein schöpft aber das Potenzial von laparoskopischen Boxtrainern nicht aus. Die Ausbildung von Weiterbildungsassistentinnen und -assistenten und von Medizinstudierenden kann mit einem Programm, in dem strukturiert Trainingszeit eingeräumt und mit einem Partner trainiert wird, verbessert werden.

Introduction

The proportion of procedures performed using minimally invasive surgery (MIS) is increasing significantly [1]. For a long time, the principle of apprenticeship was used in the surgical training of doctors. This principle presupposes an intensive trainer-apprentice relationship with intensive supervision [2, 3]. Initially, small and simple exercises are carried out; once these have been mastered, more complex tasks can be tackled.

To date, little is known about the learning processes in surgical training in laparoscopy.

Surgical technique improves with repetition. This is often described as a learning curve. At the beginning, novices have a steep learning curve, but as soon as they reach a plateau, it can be assumed that they have mastered the procedure [4]. The learning curve can be used to compare learning outcomes. Laparoscopic box trainers are used to minimize the time it takes to reach the plateau of the learning curve for operating procedures [5, 6, 7, 8, 9, 10, 11, 12]. It is expected that training on the box trainer will allow time in the operating theater to be used more efficiently, so that beginners will need less time to reliably perform surgical steps [5].

Novice laparoscopists have different levels of talent and require different numbers of repetitions before an exercise is performed reliably [3, 5]. In Germany, a mandatory curriculum for gynecological surgeons already exists for certification by the Endoscopy Working Group. This involves completing training on the box trainer and submitting surgical reports [13].

The first surgical steps in laparoscopy usually are initially done as one-handed assistance while the other hand of the resident continues to guide the camera. These are both already very complex motion patterns for a novice. Introduction to simple exercises for novices in box training emphasizes on use of both hands even in the beginning. Students rarely have the opportunity to gain practical insights into MIS and find a possible field of activity before starting their career [14, 15].

Talented trainees with an intensive trainer-apprentice relationship can proceed these motion patterns in the operating theater directly. Supposedly less talented novices will need much more time and repetitions to fulfill the procedure. These novices can spend additional time with box trainers in order to successfully repeat certain operational steps. Another positive aspect of laparoscopic box trainers is that novices do not have to carry out their first experience under time pressure and with the fear of harming the patient. The influence of time pressure is greater for novices than for experienced surgeons, even shown in simulated box training [16].

The advantage of these trainers is that they teach hand–eye coordination, the use of laparoscopic instruments and the force required for laparoscopy before the first patient contact [9, 17, 18, 19, 20].

There is already evidence from small randomized studies that a structured laparoscopy training program with institutionalization improved learning outcomes [21] and that the success of the box training lasts for several months [22]. The effectiveness of different training methods for acquiring laparoscopic surgical skills remains a vital topic of the investigation. The particular advantage of box trainers is often seen in the possibility that novices can train independently and autonomously for a personalized training tailored to their needs [11]. However, laparoscopy training programs are not adopted due to a lack of time in daily work routines [23, 24].

The aim of this study is to analyze the enhancement of laparoscopic surgical skills in laparoscopy box trainers in a systematically guided training program compared to self-directed training.

Methods

Participants

A total of 40 students with over 3500 training sessions divided in two groups were observed and evaluated during 04/2021 to 01/2023. The observational study was conducted in an ecological study design. After a joint introductory event in which students were introduced to the use of the box trainers (FORCE SENSE, Medishield) and to consent to participate in the study, the groups were divided into the self-directed and systematically guided learning groups. The first group consisted of 3 rd–5 th year medical students who attended the course voluntarily and completed a 14-weeks training. The second group consisted of last year's students who were on their gynecology elective.

The elective course for medical undergraduate students was established in accordance with the German and European training curricula for MIS. The students completed laparoscopy courses every week in tandem with a peer tutor under the intermittent supervision of an experienced surgeon. The experienced surgeon observed the students and gave feedback if any flaws were noticed. Questions about surgical techniques could be asked at any time.

The second group was at the site for a total of 4 months and were able to go to the box trainers at any time during this period to complete the training. In a weekly seminar, they had the opportunity to discuss technical or content-related issues.

Training

The recommended order of the parcourse, analogous to the training concept of the German training curriculum for MIS [13], is Post and Sleeve (1), Loops and Wire (2), Zig-Zag-Loop (3), Flap Task (4), Wire Chaser two hands (5), Wire chaser one hand (6), Intracorporeal Knot-Tying (7) and Needle Track (8).

At the beginning of each session, the participants repeated the parcourse they had already completed. It was recommended to save the best results of the parcourse each day. Both groups were free to choose which results to save.

The instructions for the course are provided with an example written and in pictures by the box trainers program. The training sessions are recorded on video. The program determines a star rating (score) based on the parameters of distance covered with both hands (path length), speed (time) and required force (compare ▶ **Table 1**). Both groups received the same instructions and feedback from the box trainers.

The outcomes included comparisons of distance covered with both hands (path length), required force, speed (time), and an overall score for both groups across the training sessions.

▶**Table 1** In this table the parameters measured in the ForceSense box training system are explained. The score showed in stars is a combination of the quantitatively measured parameters time, force, and path length.

Parameter	Description
Time in seconds	Time from start of the parcourse until its completion
Force in Newton	Highest absolute force measured on the plate of the parcourse
Path length in mm	Total distance of both instruments during the parcourse
Score in stars 1–5	Combination of the results above for a quick comparison for the participants (global rating)

The study was approved by the ethics committee of the medical faculty of Heinrich-Heine-University Düsseldorf (reference: 2021-1473). Participation had no influence on study outcomes or grades. To assess the progression of time, linear regressions with session as independent and the score as dependent variables were calculated. The analyses were conducted on an alpha = 0.05 level, and run with SPSS version 29.0.0.0 (IBM Corp., Armonk, New York) and the graphs were drawn with R version 4.1.0 (R Development Core Team, 2015).

Results

Participant demographics and data overview

A total of 3652 measurements were carried out on 40 students. The structured cohort consisted of 21 students (53 %) from the 3 rd–5 th year of study and the self-directed cohort consisted of 19 last year students in their elective (47 %). Only measurements for which time, force and path length were recorded were included in the analysis. This resulted in a total of 962 measurements with 702 measurements (73 %) in the structured and 260 measurements (27 %) in the self-directed group (see ▶ **Table 2**). The completion was monitored through the recording of the training sessions and the global star rating.

▶ **Table 2** provides the data on score, force, and path length for participants in five training exercises, divided into two groups: structured training and self-directed training. The table distinguishes the overall score, force and the path length. Each row represents a different task (Post & Sleeve, Loops & Wire, Flap Task, Wire Chaser, and Intracorporeal Knot Tying) with corresponding sample sizes, mean values, standard deviations (SD), and 95 % confidence intervals (CI) for each metric (score, force, and path length) in both training groups. Additionally, the p values for the t-tests comparing the structured and self-directed groups are provided to indicate statistical significance. In ▶ **Table 2**, it is noticeable that few events were included in the calculation, particularly for the intracorporeal knot tying parcourse. Only data for which force, time and path length were saved were included in the calculation. The students only saved their best result for each training session and the courses they started with were repeated. There-

▶Table 2 Summary of Performance Results for Structured and Self-Directed Training Groups in Laparoscopic Exercises. This table presents the comparative results of the structured (Struct) and self-directed (Selfdir) training groups in five laparoscopic exercises (Post & Sleeve, Loops & Wire, Flap Task, Wire Chaser, One Hand, and Intracorporeal Knot Tying). Only training sessions that were independently logged by participants and where performance values did not significantly deviate from the average are included. The table compares the mean scores, force exertion, and path length, along with standard deviations (SD) and 95 % confidence intervals (CI), to assess differences in performance consistency between the two groups. Statistically significant differences (p < 0.05) are indicated where applicable.

Parcourse	Post & Sleeve		Loops & Wire		Flap Task		Wire Chaser One Hand		Intracorporeal Knot Tying	
	Struct (n = 276)	Selfdir (n = 86)	Struct (n = 236)	Selfdir (n = 82)	Struct (n = 123)	Selfdir (n = 41)	Struct (n = 54)	Selfdir (n = 41)	Struct (n = 3)	Selfdir (n = 3)
Score										
Mean	3.23	3.16	3.33	3.32	3.85	3.59	3.43	2.59	0.83	0.68
SD	0.96	0.98	0.92	0.76	0.85	0.85	1.03	0.98	0.33	0.27
95 % CI	3.12; 3.45	2.85; 3.37	3.22; 3.45	3.16; 3.49	3.70; 4.00	3.33; 3.86	3.15; 3.71	2.28; 2.89	0.01; 1.65	− 0.02; 1.34
p value		0.557		0.930		0.092		< 0.001 *		n.a.
Force										
Mean	0.24	0.40	20.16	18.85	3.67	0.73	10494	13275	34.02	89.40
SD	0.08	0.62	8.18	7.20	6.10	0.19	3139	3463	10.31	91.84
95 % CI	0.23; 0.25	0.26; 0.53	19.11; 21.21	17.27; 20.43	2.58; 4.76	0.66; 0.79	9637; 11351	12183; 14370	8.41; 59.63	138.75; 317.55
p value		0.003 *		0.171		< 0.001 *		< 0.001 *		n.a.
Path length										
Mean	7465	7885	0.33	0.41	1001	6.34	5331	7554	244.50	273.57
SD	2371	3035	1.54	2.88	1989	15.86	1697	2413	55.49	45.97
95 % CI	7184; 7746	7234; 8536	0.13; 0.53	−0.22; 1.05	645; 1356	1.33; 11.35	4868; 5794	6792; 8316	106.7; 382.3	159.38; 387.79
p value		0.156		0.722		< 0.001 *		< 0.001 *		n.a.

Abbreviations: CI = Confidence Interval; LB = Lower Bound; n.a. = not applied due to small sample size; SD = Standard Deviation; Selfdir = Self-directed Training; Struct = Structured Training; UB = Upper Bound; p value
* = significant result

fore, intracorporeal knot tying was practiced less frequently and often practiced first and then recorded once per training session.

Comparison of performance scores and consistency

The statistical analysis involved conducting independent t-tests to compare the mean scores, force, and path lengths between the structured and self-directed training cohorts across six different tasks. The p values obtained from these tests indicate whether the differences between the two groups were statistically significant.

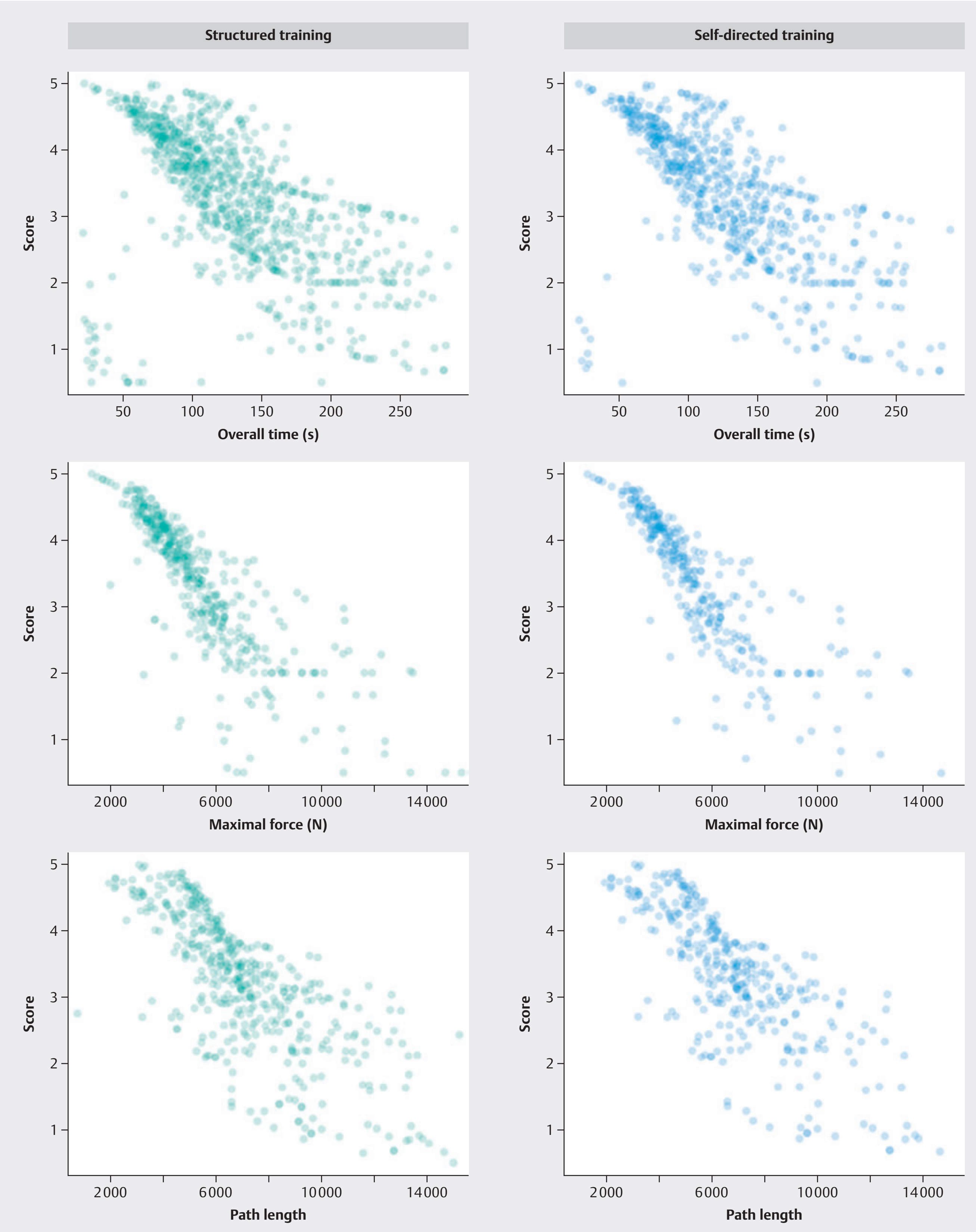
Considering the score, the structured participants achieved higher results on average with a lower standard deviation, which indicates a better consistency of performance. This applies to the parcourse Post and Sleeve ($p = 0.557$), Wire Chaser ($p \leq 0.001$) and Flap Task ($p = 0.092$). Only in the task Wire Chaser the difference was significant.

Force application and variability

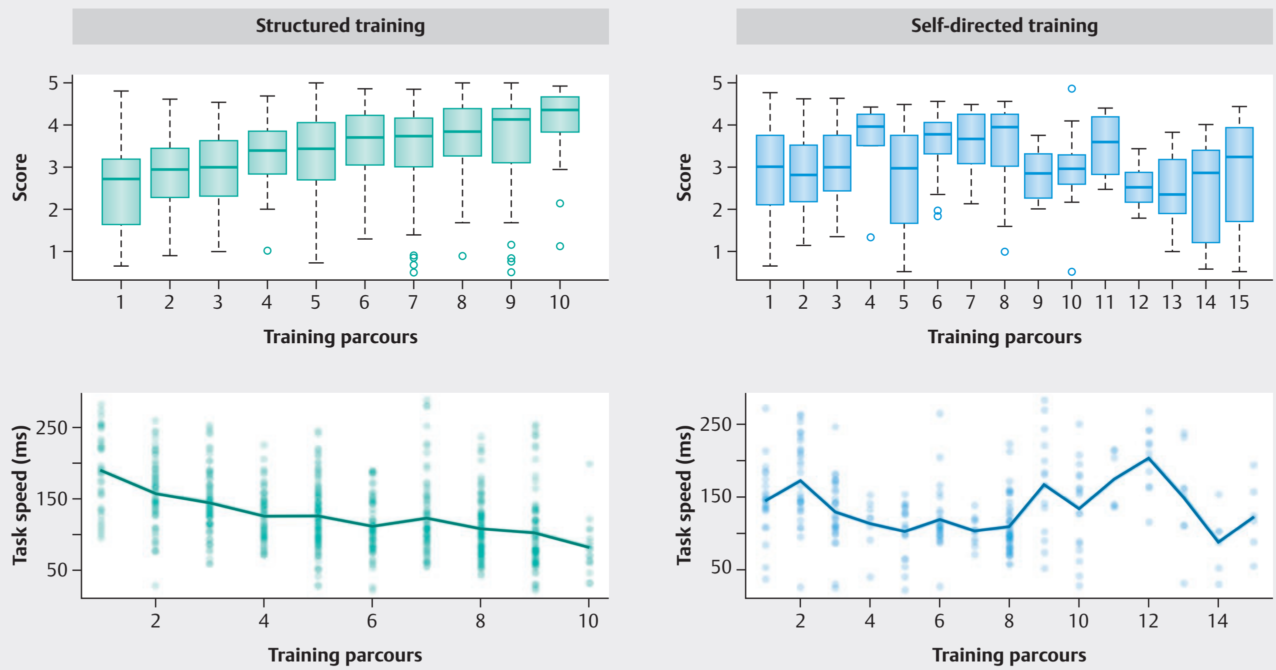
Self-directed participants exerted more force with much higher variability in the parcourse Post and Sleeve ($p = 0.003$) and Wire Chaser ($p \leq 0.001$). In comparison the structured group exerted significantly more force, with higher variability in the parcourse Flap Task ($p \leq 0.001$) and Loops and Wire ($p = 0.171$). For the path length measurement, the self-directed group had longer path lengths with higher variability in the parcourse Post and Sleeve ($p = 0.156$), Loops and Wire ($p = 0.722$) and Wire Chaser ($p \leq 0.001$). Structured training participants were significantly more efficient in their movements for the task Wire Chaser.

Overall, the structured training group appears to have better performance in terms of scores and consistency, while the self-directed group exhibits higher force application and motion variability.

In a first step, it was tested whether the score corresponds to the measured results. ▶ **Fig. 1** shows the linear correlation between the overall score and the individual measurement parameters time, force and path length. Since the score is linearly related to the measured parameters, the score was used for an overall comparison in the linear regression (compare ▶ **Fig. 2**).



▶ **Fig. 1** This figure presents the parameters of time, force, and path length to illustrate their relationship within the overall star scoring system. The data demonstrate how these raw performance metrics contribute to the final scores and highlight the linear correlation between the individual parameters and the overall performance ratings.



▶ **Fig. 2** Visualization of the Training Progress and Consistency over the Completed Training Sessions Demonstrated with the Parameter Speed and Global Rating Score. The development of the parameters overall score (upper part) and time (lower part) in relation to the completed training sessions on the left side for the structured group and on the right side for the self-directed group is demonstrated. This figure shows that the structured group shows a more consistent outcome in overall performance with fewer training sessions.

Progression over time

In the structured cohort, the number of 10 training sessions was predetermined. Compared to the structured cohort, the self-directed cohort trained more frequently on average (compare ▶ **Fig. 2** with average of 15 sessions in self-directed cohort vs. 10 sessions in structured cohort).

The results of the groups were also observed over the entire period of their training session, with equally high variability in the results of the self-directed group as shown in ▶ **Table 2** divided for each parcourse.

The structured cohort showed a continuous improvement over time. The self-directed cohort showed no sustained improvement over the training sessions (see ▶ **Fig. 2**). In the global rating score, which is determined from the parameters of time, force exerted and path length, the structured group showed a continuous improvement on average, $F(1,700) = 75.457$, $p < 0.001$, $R^2 = 0.109$, compared to the self-directed cohort, in which no continuity could be seen even with more training sessions, $F(1,258) = 0.098$, $p = 0.755$, $R^2 = -0.003$ (see ▶ **Fig. 2**).

Discussion

This study investigates the enhancement of laparoscopic surgical skills in laparoscopy box trainers in a systematically guided training program compared to self-directed training.

Multiple studies have already shown that box trainers help to improve skills and increase the learning curve, but often studies have only been carried out selectively with young surgeons over a few days or weeks and little attention has been paid to the external conditions when designing the training [2, 3, 4, 6, 9, 10, 11, 22].

In contrast, this study was able to show the improvement in the skills of medical students in preparation for MIS and thus promotes the implementation of the teaching of practical surgical skills during medical school.

To allow continuous measurement, the ForceSense system from Medishield in accordance with the guidelines of the German Endoscopy Working Group of MIS was used for the box training in this study. This allows a deeper insight into the learning effects of the students and enables a better understanding of the learning curve. The ForceSense system is the first system to objectively assess laparoscopic skills. In the study by Hardon et al., after an introduction, the box trainers were taken home for three weeks to train at least four times a week for at least 15 minutes. The results of this study show an improvement in all first-year surgeons [10].

It is extensively discussed that trainee surgeons can use the time in hospital in the operating room and can train flexibly outside of working hours with home-based programs. The high flexibility of the novice training and the reduced personnel costs for the program to maintain a skills lab are cited as particularly advantageous.

In the study by Hardon et al., it is noticeable that there is a group of poor performers that differ from the rest. The group has a significantly less steep learning curve, still improves over the three weeks and reaches the expected exam target, but performs worse than its peers [11]. Compared to the available data from the present study, these students could benefit from structured or institutionalized training. There are currently no known characteristics to identify members of this group beforehand.

The present study provides evidence for the hypothesis that structured and guided laparoscopic simulation training programs are more effective than unstructured training.

Based on our results it could be concluded that the implementation of practical surgical training must be didactically embedded in the educational program and that mere availability of training sites does not exploit the potential of laparoscopic box trainers.

The Dutch study group led by Hardon et al. also published a multicenter study by Rahimi et al., in which the individual learning curve could be predicted after three initial training sessions [5]. This is only possible with a measurement system that can objectively measure force, time and path length. Here, individual skill training is primarily related to the number of repetitions required. The available data in the present study suggest that supervision and collaborative work also have an influence on the success of the objectively measured results.

In case of poor results, Hardon et al. suggests investigating psychomotor reasons in novices and considering whether novices are prepared to work independently in the operating room [10]. Alternatively, the low-performing novices could also benefit from a more institutionalized training curriculum and could develop better under structured conditions, analogous to the data presented here.

In a Canadian study, gynecology residents were asked about their use of laparoscopy trainers. The rate of simulator use was found to be less than 10 hours in the last 12 months. Reasons given for this were lack of time, lack of supervised training and difficult accessibility [23]. These results indicate a desire for more structured training and suggest that residents would also welcome institutionalization in laparoscopic training [24].

Surgical simulation training results in a high stress level in inexperienced surgeons [25]. Structured training with peers could help to comfort novices with their stress levels. Further studies should be initiated.

Limitations

The two groups in the study received different amounts of guidance, so that 75% of the measurements fall on the structured training group, although the structured training group had fewer training sessions. The self-directed cohort was not told how long a training session should be and how many training repetitions they should perform. It was not checked whether they repeated the previous training sessions. The training sessions were performed at their own discretion in addition to the four-month-elective in the department. The participants were allowed to decide which training results they wanted to save. It was recommended to save the best score from each training session. In the self-directed cohort, the saving of sessions was not monitored. It is not possible to draw conclusions from the data collected as to how long the students spent using the box trainer per training session, as they did not have to save every training. These could be possible reasons for the relative difference in the number of measurements in the two groups. The self-directed group had one year more clinical experience and more contact with surgeries and procedures in the operating theater, so better training results could be expected. Despite more clinical experience and high motivation, the results during the training sessions were inferior to those of the structured group. It can therefore be concluded that self-directed training is less efficient.

In the structured approach, a continuous improvement in performance was observed in fewer training sessions. In further research work, the students should initially be assessed to build equal groups to avoid a selective bias.

According to a literature review, this study is the largest sample and longest observed time period of a laparoscopy training in medical students.

Conclusion

Setting up a box trainer alone without a suitable curriculum, does not reach the full potential of the training intervention. Based on the available data, it can be assumed that institutionalized training with a structured time constraint and a training partner will show an improved outcome compared to unsupervised training.

The intervention of giving inexperienced novices a training opportunity does improve their practical skills in all available studies. However, this study was able to show that institutionalizing the teaching unit with little additional effort on the part of the training center clearly stabilizes and strengthens the continuity of learning success.

It remains unanswered which factors are ultimately decisive for the improved outcome of the structured group in this study and should be assessed in more detail in further studies nor can this study answer whether the results can be transferred to young surgeons. However, it is encouraged that when creating a curriculum either for young surgeons or medical students a fixed training time slot and a collaborative approach should be chosen.

Conflict of Interest

The authors declare that they have no conflict of interest.

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