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ORIGINAL ARTICLE

Defining a structured training program for acquiring basic and advanced laparoscopic psychomotor skills in a simulator

Carlos Roger Molinas · Rudi Campo

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Abstract The effect of different structured training programs on basic laparoscopic psychomotor skills (LPS), as assessed by hand–eye coordination (HEC), and on advanced LPS, as assessed by laparoscopic intracorporeal knot tying (LICK), was evaluated. Sixty gynecologists without laparoscopic experience were randomly allocated to three groups for different HEC training and similar LICK training. During HEC training, group 1 (G1) trained the dominant hand (DH) and the nondominant hand, G2 trained the DH only, and G3 did not train at all. All groups then underwent LICK training. HEC and LICK training consisted of 60 repetitions of the relevant task. All participants were tested at the beginning of the study (T1), before LICK training (T2), and after LICK training (T3). The time to correctly performed exercise was scored. The groups had comparable scores at T1. At T2, G1 and G2 improved their relevant HEC scores (both hands in G1, DH in G2), and LICK scores improved according to the previous HEC training (G1 > G2 or G3 and G2 > G3). At T3, all groups further improved their LICK scores up to the same level. The LICK training did not provide any additional improvement in HEC for G1 and G2, but it further improved HEC for G3, though not up to the same level of the other groups. This study confirms that training improves laparoscopic skills and indicates that many repetitions are required for reaching proficiency. Full acquisition of LPS (e.g., HEC) facilitates the acquisition of more complex laparoscopic tasks (e.g., LICK). Mastering LICK is not sufficient for acquiring HEC skills, the clinical relevance of which still needs to be evaluated. Mastering both skills before starting a training program in the operating theater is advisable.

Keywords Laparoscopy · Training · Psychomotor skills · Intracorporeal knot tying · Hand–eye coordination · Simulator

C. R. Molinas · R. Campo
European Academy of Gynaecological Surgery,
Leuven, Belgium

C. R. Molinas (✉)
Centre for Gynaecological Endoscopy, Centro Médico La Costa,
Asunción, Paraguay
e-mail: roger.molinas@lacosta.com.py

R. Campo
Leuven Institute for Fertility and Embryology,
Leuven, Belgium

Introduction

Laparoscopy is rapidly replacing laparotomy in both gynecological and abdominal surgery. Unfortunately, there is concern that laparoscopic techniques are related to an increase in patient morbidity and mortality. To ensure patient's safety, it seems obvious, though not yet implemented, that a future laparoscopist should possess objectively measurable theoretical and practical skills. In addition to the surgical skills required for open surgery, which includes manual dexterity, and the knowledge of anatomy, pathology, and surgical techniques, laparoscopy also demands specific laparoscopic psychomotor skills (LPS). These skills are required for working in a key-hole environment in which the tactile feedback, three-dimensional vision, and freedom of moving the hands and instruments are missing. Indeed, laparoscopy demands the ability of depth appreciation on a two-dimensional screen using subtle visual clues, hand–eye coordination, bimanual coordination, ambidexterity, and handling long instruments from a fixed position.

The effective acquisition of skills, both surgical skills and pure LPS, is essential for minimal access surgery to be a minimally invasive surgery and can only be achieved with appropriate training. Achieving proficiency in LPS and the performance of typical surgical maneuvers, such as laparoscopic suturing and knot tying, through the classic apprenticeship system seems not only impossible, but also ethically unacceptable, because it increases the operating time and complication rate. Therefore, more and more specialists agree that part of this training has to be done outside the operating room (OR), and different models have been proposed [1–8].

Both trainer boxes and virtual reality models allow for relaxed and controlled training, and learning curves for different laparoscopic tasks have been reported [9–11]. Trainer boxes are relatively cheap and accessible [4], whereas virtual reality models provide an objective evaluation of the learning process [12], with both being equally effective for acquiring laparoscopic skills [7]. Animal models seem ideal, but they are not widely and routinely used due to financial and ethical restrictions. In contrast to animal models that are normally used for short periods (e.g., 2–3 day courses), inanimate models have an advantage of allowing for longer training periods, which is crucial to ensuring full LPS acquisition and not only exposure to specific laparoscopic tasks.

The European Academy of Gynaecological Surgery recently developed the Laparoscopic Skills Testing and Training (LASTT) model aimed to specifically train and measure some LPS: camera navigation (CN), hand–eye coordination (HEC), and bimanual coordination (BMC) [13]. This model can be a cost-effective tool for continuous training and evaluation of LPS in all surgical disciplines that perform laparoscopic procedures because it is tutor independent, relatively cheap, and suitable for any trainer box. Furthermore, the feasibility, construct validity (the capacity of the method to distinguish between experienced and inexperienced surgeons) [13], and face validity (the realism of the method) [14] of the model has been well demonstrated.

Mastering basic LPS can be assumed to facilitate the acquisition of more complex and advanced LPS, eventually improving the quality of the surgery, but the extent to which this is important remains unquantifiable. This study was designed to evaluate the effect of different structured training programs on both basic and advanced LPS acquisition and to assess the effect of one type of skill on the other. The study was conducted in a population with no laparoscopic experience. For assessing basic LPS a task for HEC was used, whereas laparoscopic intracorporeal knot tying (LICK) was used to assess more complex and advanced LPS.

Materials and methods

Participants and venue

The study was carried out between December 2006 and June 2007 in the Centro Médico La Costa in Asunción, Paraguay and included 60 physicians randomly allocated to three different groups according to the experimental design. Inclusion criteria were the following: specialists or residents in obstetrics and gynecology, 26–45 years old, experienced in classic suturing and knot-tying techniques, and little or no experience in laparoscopic surgery (level 0–1 of the European Society of Gynaecological Endoscopy classification) [13]. Age, gender, training status (i.e., residents or specialists), and dominant hand (DH) and nondominant hand (NDH) sides were recorded for each participant.

Instruments and materials

The study was conducted in two identical stations fitted with a Telepack (monitor, camera, and light source), 10 mm 0º optic, 5 mm Kelly forceps, 5 mm Koh needle holders with right and left curvature, and a Szabo trainer box (Karl Storz, Tutlingen, Germany). The working stations were mounted with the materials required for the relevant laparoscopic tasks.

Laparoscopic tasks

Basic LPS A validated exercise for HEC in the LASTT model was used to assess this type of skills. A participant's ability to navigate a laparoscopic camera with 0º optic and to handle laparoscopic forceps with the DH or NDH was evaluated. We measured the ability to grasp and transport six objects to six targets in the LASTT model fitted with colored objects (5×4 mm open cylinders) and colored targets (10×1 mm nails) as described previously [13, 14]. The matched targets and objects were identifiable by color. The participant stood behind the trainer box in the midline. The optic was introduced through a midline port and Kelly forceps through a lower and lateral port, to the right or the left according to the hand being evaluated. The Kelly forceps was held with the hand being evaluated and the camera with the contralateral hand. Participants were allowed to start the task when the first target and tip of the Kelly forceps were shown on the screen (start time). The first object was grasped and transported to its target. Only when the participant succeeded in introducing the first cylinder into the first nail was he/she allowed to continue with the others in a fixed order.

The time for each repetition was limited to 600 s. The task finished either when the last object was transported to its target or when the time limit expired. Because the active part of the task demands the use of only one hand, it was executed and scored separately for the DH and NDH, respectively. The time required to successfully finalize the task, referred to as time to correctly performed exercise (TCPE), ranged from 0 to 600 and was used to score the exercise. Since some participants may not successfully execute the task within this time limit, the final score was calculated as follows: If the task was successfully executed, the time actually used was divided by 1. If the task was not successfully executed, the maximum time used (i.e., 600 s) was divided by 0.5, giving a final score of 1,200. This was done to clearly differentiate the failed repetitions from repetitions successfully executed in the maximum time.

Advanced LPS A LICK task was used to assess this type of skills. A soft pad with two premounted sutures (vicryl 2–0, 20 cm length), 1 cm between entry and exit sites, and tails equally distributed at both sites was fitted in the Szabo trainer box in a horizontal position. The optic was introduced through a midline port and the needle holders through lower and lateral ports to the right for the left curve (right needle holder) and to the left for the right curve (left needle holder). The participant stood to the left of the trainer box. The camera was fixed at a distance that allowed visualization of the entire operating field. The needle holders were held with the relevant hands and the knot was made using the gladiator technique [15]. The tip of the thread was grasped with the left needle holder and the thread was pulled through the pad, leaving a 2-cm tail on the opposite side. Then, a double counter-clockwise knot was made, followed by a single clockwise knot and, finally, by a single counter-clockwise knot.

The time for each repetition was limited to 600 s. The task was finished either when the participant considered he/she completed the knot or when the time limit had expired. When the task was finalized, the tutor performed quality control. The knot was considered correctly tied when a needle holder introduced between the knot and the underlying pad did not reveal any free space and when it was not possible to untie it with upwards force exerted by the needle holder. If the knot was successfully executed within the time limit, the final score was calculated dividing the time actually used by 1. If a correct knot was not achieved within the time limit, the final score assigned was 1,200, which was obtained by dividing the maximum time (i.e., 600 s) by 0.5.

Experimental design

Participants received a full explanation and video demonstrations of both tasks at the beginning of the study. Although a tutor was standing next to the participant at each working station, no further instructions were given during the performance of the exercises.

Each repetition of the task demanded 100% efficacy (i.e., the repetition was considered complete and valid only after a successful performance), allowing the measurement of only one parameter (i.e., TCPE) in which the errors and economy of the movements will be reflected. For HEC, the assessment of this efficacy was obvious for both the participant and the tutor; therefore, the former was allowed to correct any possible mistake within the time limit. However, for LICK, the assessment of efficacy demanded quality control by the tutor, which could only be done after finalizing the repetition. Therefore, the participant was allowed to make any correction he/she considered necessary to obtain a good knot within the time limit, and the time was stopped when the participant indicated he/she had finished the knot, which was validated after tutor evaluation.

Participants were randomly allocated to three different groups (n=20 per group) to follow different HEC training programs and similar LICK training programs. In group 1 (G1), participants performed 60 repetitions of HEC with the DH and 60 repetitions of HEC with the NDH in alternating orders. In group 2 (G2), participants performed 60 repetitions of HEC with the DH only. In group 3 (G3), participants did not perform any HEC training, neither with the DH nor with the NDH. Afterwards, all participants followed a LICK training program consisting of 60 repetitions (Fig. 1). Since the aim was to ascertain that most participants reach the plateau of the learning curve, this number of repetitions was decided based on previous data indicating that many participants still did not reach this plateau after 30 repetitions [13].

All participants were tested for HEC with the DH, HEC with the NDH, and LICK at the beginning of the study (T1), immediately before LICK training (T2), and immediately after LICK training (T3; Fig. 1). Each test consisted of three repetitions of the relevant task, and the average of the triplicate observations was used for statistical analysis.

Testing sessions (T1, T2, and T3) were organized as independent sessions lasting around 1.5 h for each participant. In order to optimize the results, training sessions of 1.5 h were organized for every 1–3 days (unpublished data). The number of sessions and repetitions performed at each session was variable and dependent on a participant's skills.

Statistical analysis

Unless otherwise indicated, all data are presented as mean± SE. All statistical comparisons were performed using the Graph Pad Prism Software and two-tailed p values <0.05 were considered significant.

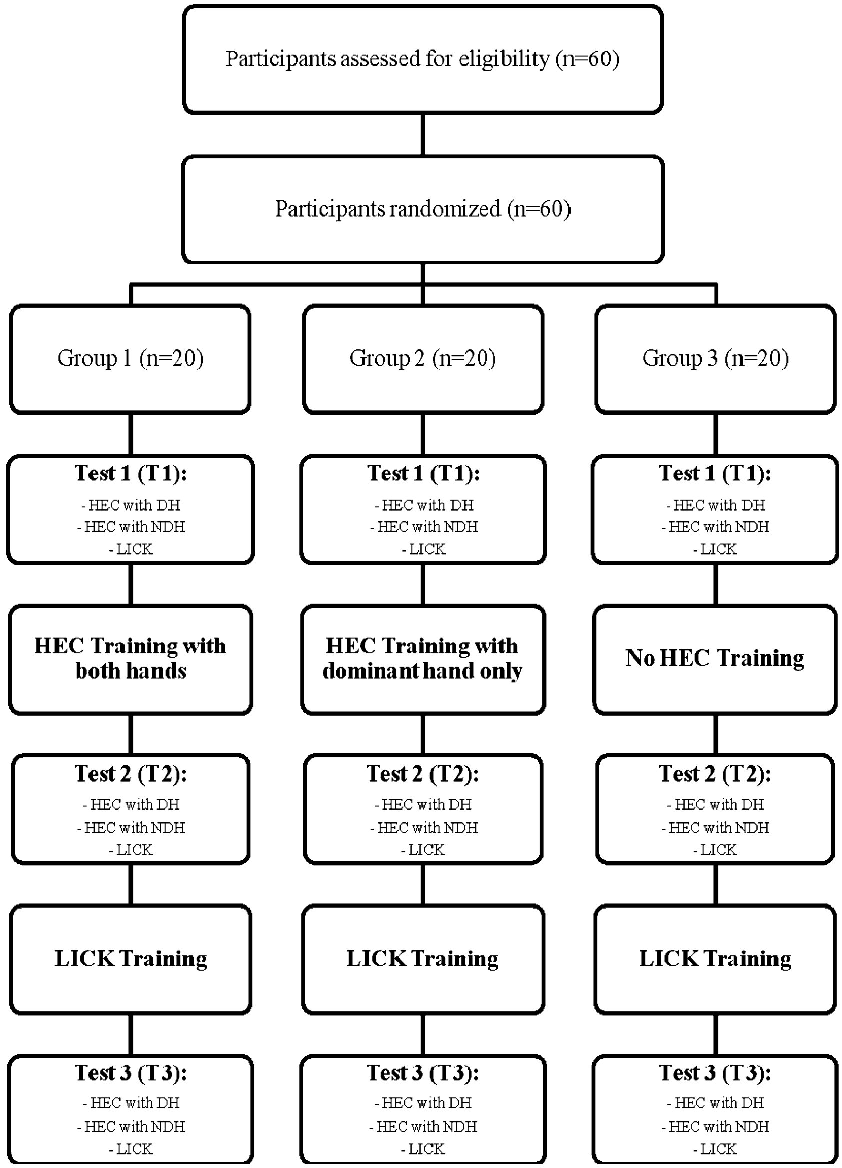

Fig. 1 Flow chart of performing test and training

HEC analysis Intragroup differences between the DH and the NDH at T1, T2, and T3 were assessed by paired *t* tests. Intragroup differences between T1, T2, and T3 were also assessed by paired *t* tests. Intergroup differences at T1, T2, and T3 were assessed by one-way analysis of variance with Bonferroni's correction for multiple comparison tests.

LICK analysis Intragroup differences between T1, T2, and T3 were assessed by paired *t* tests. Intergroup differences at T1, T2, and T3 were assessed by one-way analysis of variance for parametric data with Bonferroni's correction for multiple comparison tests and by the Kruskal–Wallis test for nonparametric data with Dunn's correction for multiple comparison tests.

The effects of surgeon characteristics (age, gender, training status, dominant hand side) on changes in scores were evaluated by fitting regression models for the differences between the scores measured at T1 and T2, T2 and T3, and T1 and T3. The correlation between HEC with the DH and the NDH, HEC with the DH and LICK, and HEC with the NDH and LICK was evaluated by the Spearman test.

Results

The median age of the participants was 29 years (range 26–45 years) and gender was evenly distributed (50% males, 50% females, $n=30$ each). The number of specialists ($n=20$, 40%) was less than the number of residents ($n=40$, 60%). As expected, the number of right-handed participants ($n=55$, 92%) was greater than left-handed participants ($n=5$, 8%). The demographics of the three study groups are presented in Table 1.

Table 1 Participant demographics

	Group		
	G1 (n=20)	G2 (n=20)	G3 (n=20)
Age (years), median (range)	29 (26–45)	29 (26–37)	32 (27–45)
Gender (%)			
Male	12 (60%)	9 (45%)	9 (45%)
Female	8 (40%)	11 (55%)	11 (55%)
Training status (%)			
In-training	13 (65%)	16 (80%)	11 (55%)
Specialist	7 (35%)	4 (20%)	9 (45%)
Dominant hand side			
Right	19 (95%)	17 (85%)	19 (95%)
Left	1 (5%)	3 (15%)	1 (5%)

HEC training

At the beginning of the study (T1), the DH scores were similar in the three groups (G1, 187±16; G2, 172±16; G3, 182±17; $p>0.05$, Fig. 2), as were the NDH scores (G1, 308±41; G2, 313±49; G3, 300±55; $p>0.05$, Fig. 2). The DH scores were better than the NDH scores in all groups (G1, $p=0.01$; G2, $p=0.003$; G3, $p=0.01$).

At T2, the scores improved significantly according to the different training programs. In G1, the DH score decreased to 44±2 ($p<0.0001$) and the NDH score decreased to 54±2 ($p<0.0001$). In G2, the DH score decreased to 51±3 ($p<0.0001$) and, interestingly, the NDH score also decreased, though only to 102±8 ($p=0.0003$). Surprisingly, G3 had a slight improvement in skills; the DH score decreased to 115±8 ($p=0.001$) and the NDH score decreased to 167±17 ($p=0.01$).

The DH scores for G1 and G2 were similar ($p>0.05$) but better than the score for G3 ($p<0.001$ for both). The NDH score for G1 was better than the scores for G2 and G3 ($p<0.01$ and $p<0.001$, respectively), and the score for G2 was better than the score for G3 ($p<0.001$).

At T2, the DH scores remained better than the NDH scores in all groups independent of the type of HEC training performed (G1, $p<0.0001$; G2, $p<0.0001$; G3, $p=0.004$).

Effect of HEC on LICK

The LICK scores at the beginning of the study (T1) were similar in the three groups (G1, 395±61; G2, 455±85; G3, 445±86; $P>0.05$, Fig. 1). At T2, the LICK scores for G1 decreased to 93±7 ($p<0.0001$), but they only decreased to 217±64 for G2 ($p=0.004$) and 265±72 for G3 ($p=0.01$). The LICK score for G1 was better than the scores for G2 and G3, but the difference was only significant between G1 and G3 ($p<0.001$). The LICK score for G2 was better than the score for G3, but it was not significant.

LICK training

After the specific and standard LICK training of all three groups, a major improvement in the participants' skills was observed at T3 (Fig. 2). The scores decreased to 37±2 in G1 ($p<0.0001$), 36±2 in G2 ($p=0.01$), and 38±3 in G3 ($p=0.005$) without intergroup differences ($p>0.05$).

Effect of LICK on HEC

The full LICK training had different effects on the three groups in regards to the HEC skills measured at the end of the study (T3; Fig. 2). Achieving proficiency in LICK did not provide any additional improvement in HEC in those who already achieved proficiency in this skill (i.e., G1). Furthermore, the LICK training was not sufficient for achieving proficiency in HEC or to compensate for the intergroup differences in HEC.

No additional improvement in HEC was seen for G1 after LICK training, and the HEC scores at T3 remained comparable to those observed at T2 (45±2 for the DH, $p>0.05$; 59±3 for the NDH, $p>0.05$).

No additional improvement in HEC with the DH was seen for G2, and the score remained at 46±2 ($p>0.05$). However, the NDH score of G2 decreased to 74±3 ($p=0.005$) after LICK training.

The HEC scores for G3 improved after LICK training. The score decreased to 90±7 ($p=0.0004$) for the DH and to 114±8 for the NDH ($p=0.002$).

The HEC scores for the DH for G1 and G2 remained similar ($p>0.05$) and better than the score for G3 ($p<0.001$ for both). The NDH score for G1 remained better than the score for G2, but it was not significant, whereas the scores

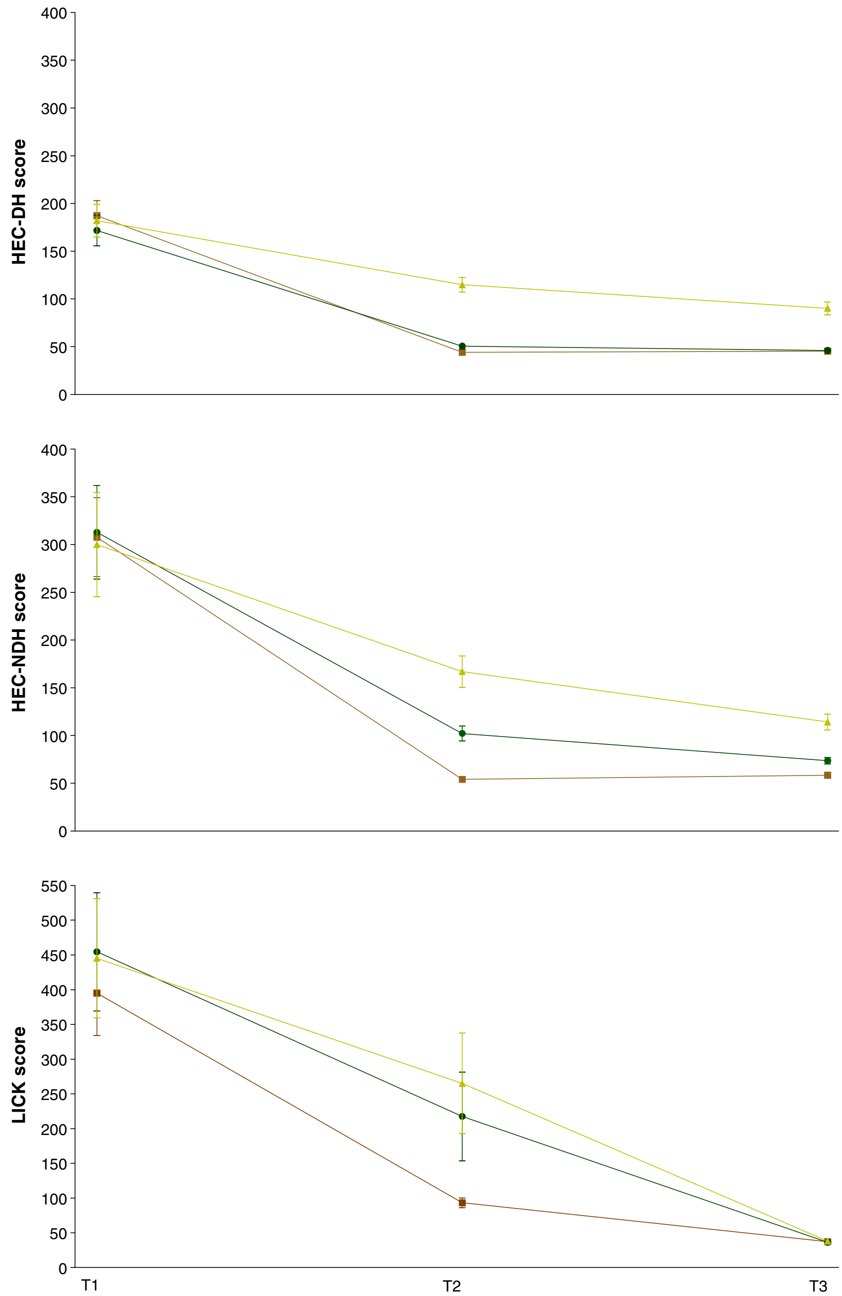

Fig. 2 Task scores for the three training groups at the first (T1), second (T2), and third (T3) testing times. *Top*, scores for the hand–eye coordination (HEC) task with the dominant hand (DH); *center*, scores for the HEC task with the nondominant hand (NDH); *bottom*, scores for the laparoscopic intracorporeal knot tying task (LICK). Participants were exposed to different HEC training programs between T1 and T2: G1 (*brown*), training for both DH and NDH; G2 (*green*), training for DH only; G3 (*yellow*), no training. The three groups were exposed to an identical training program for LICK between T2 and T3. Data are mean±SEM of triplicate observations

for both G1 and in G2 remained better than the score for G3 ($p<0.001$ for both).

At T3, the HEC scores for the DH remained better than the scores for the NDH in all groups (G1, $p<0.0001$; G2, $p<0.0001$; G3, $p<0.0001$).

After correcting for the training group, none of the score changes were affected by the surgeons' gender, training status, dominant hand side, or age.

Taking all data together (all groups at the three testing phases; Fig. 3), a strong correlation was observed between HEC with the DH and HEC with the NDH ($r=0.89$, $p<0.0001$), HEC with the DH and LICK ($r=0.66$, $p<0.0001$), and HEC with the NDH and LICK ($r=0.69$, $p<0.0001$).

Discussion

This study was designed to evaluate whether full acquisition of LPS facilitates the acquisition of more complex and advanced laparoscopic skills. The LASTT model was designed for evaluating three different tasks (CN, HEC, and BMC), but for the aims of this study only the HEC task was chosen to assess basic LPS, whereas advanced skills

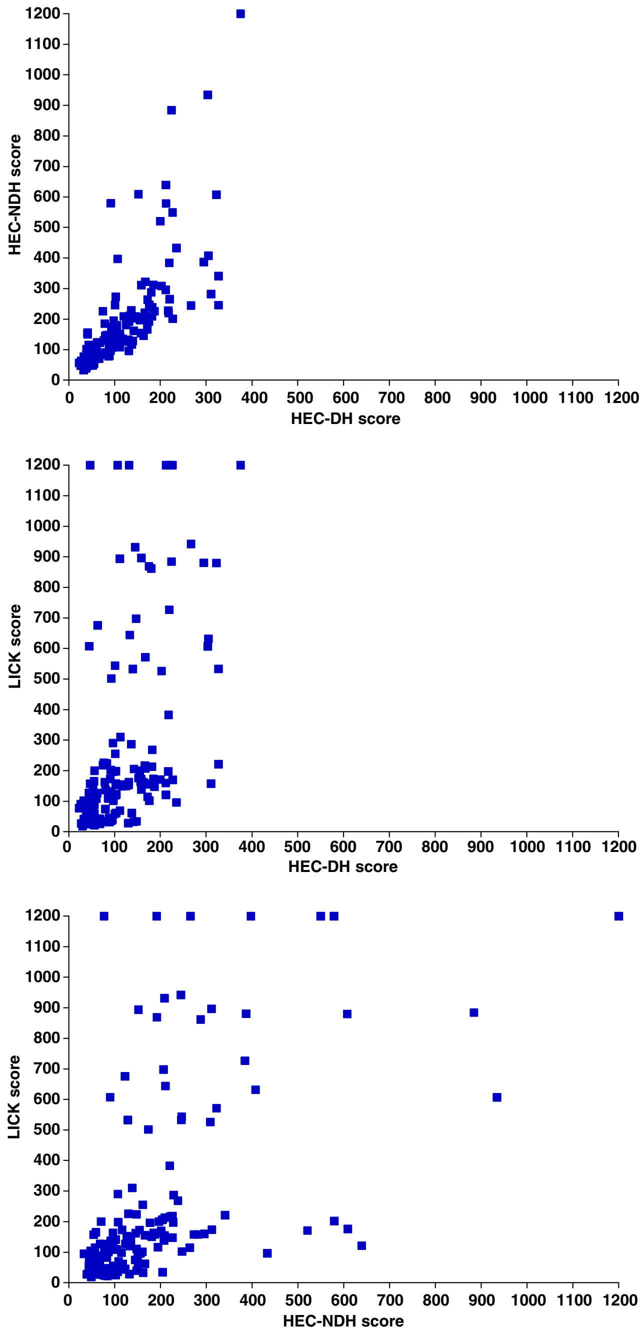

Fig. 3 Data for all participants in all three groups at the three time points. *Top,* correlation between hand–eye coordination (HEC) with the dominant hand (DH) and HEC with the nondominant hand (NDH); *center*, correlation between HEC with the DH and laparoscopic intracorporeal knot tying (LICK); *bottom*, correlation between HEC with the NDH and LICK. Each value represents the mean of triplicate observations

were assessed by a LICK task. Although these assessments can be done in different models, the setup used in this study offers the advantages of being simple, cost friendly, and easy to implement at any location and had proven construct [13] and face validity [14]. We are fully aware that, in addition to TCPE, other parameters, such as errors and economy, can influence the final performance of the task and still need to be specifically studied. We have decided, however, to not measure the other parameters quantitatively (e.g., computerized model) or semiquantitatively (e.g., Objective Structured Assessment of Technical Skills) because they were assumed to have been reflected in the TCPE.

The study was carried out in a virtually virgin population in regards to laparoscopic experience, but one with sufficient experience in classic surgical suturing techniques in which we could ascertain no exposition to any other type of laparoscopic procedures during the entire duration of the study besides those offered by the study itself. This special population, which is not easily available nowadays, allowed us to avoid the effect of confounding variables that could move the data in one direction or another and to detect differences without a large sample size.

Our data for both tasks demonstrate that, in all groups, training improves laparoscopic skills, confirming previous reports for basic LPS [10, 13] and LICK [11, 16]. In contrast with other studies that have reported better results in males and right-handed persons [17], our results were not influenced by gender or DH side. The results were also not influenced by age or training status (resident or specialist).

Interestingly, the HEC data demonstrate that very few task repetitions (i.e., three repetitions during T1 and three repetitions T2) already provide some learning effect, though not to the same level as full training. Indeed, those who did not train HEC (G2-NDH, G3-DH, and G3-NDH) had improved at T2 but not to the same level as those who performed the full training (G1-DH, G1-NDH, and G2-DH). Furthermore, the fully trained groups did not exhibit any further improvement at T3, whereas the less trained groups registered an additional improvement at T3 after the full LICK training. This finding indicates that, once a level of excellence for HEC is achieved, further training is no longer relevant for improving this particular task and LICK training improves HEC, but without fully compensating for the specific full training. Whether this latest observation is clinically relevant still has to be evaluated.

As would be anticipated by common sense, our results confirm that the HEC skills of the DH are better than the skills of the NDH. Although this difference was maintained throughout the study, the changes in the NDH were greater than the changes in the DH, emphasizing that full training for the NDH is advisable to acquire an optimal skill level. This conclusion is fully consistent with a recent report indicating the importance of a flexible and adapted curricula (length, frequency, etc.) for accomplishing proficiency [18].

Similar to HEC, the LICK data demonstrate that few task repetitions already provide a learning effect. However, because the scores at T2 varied significantly between the groups, a major impact of previous full HEC training is evident in the observed improvements. Indeed, the scores at

T2 were better for those who trained both the DH and NDH than those who only trained the DH or who did not train any hand. This finding indicates that HEC training facilitates the acquisition of LICK skills (i.e., better starting point and faster to reach proficiency). After the full LICK training, a slight (G1) or significant (G2, G3) further improvement was observed at T3, confirming that full training is still required for mastering the task.

The individual profiles of the study participants were not similar within each group, as demonstrated by the large variability at the beginning of the study, and not every participant or every group reached the reported mean values in the same way and at the same speed. Therefore, specific and detailed evaluation of the learning curve characteristics (e.g., type of curve, slope, plateau, etc.) and potential influencing factors, such as tutor feedback [19], are required before we are able to postulate the optimal duration of training for acquiring proficiency and maximizing the learning effect. It also remains to be evaluated if the observed effect of HEC upon LICK would be the same if CN or BMC or the three LPS together (i.e., CN, HEC, and BMC) would be used in this study. Whether these observations of skill acquisition are relevant for skill retention also remains unclear [20].

Our study confronted the objective of most training courses: exposing the trainee to a task (few repetitions) with the objective of ascertaining the full acquisition of the task (many repetitions). Our results indicate the relevance of many repetitions for reaching an optimal level, similar to previously reports in animal models [8, 21], which is virtually impossible in the classic 2–3 day hands-on training courses. In addition, our findings highlight the importance of proper validation, data evaluation, and documentation, which is in sharp contrast with most training courses that are evaluated by participant satisfaction only and with insufficiently documented results.

Because training courses are not easily available worldwide, and because of the above mentioned limitations (short duration and lack of validation, evaluation, and documentation), the classic apprentice–tutor model is still the most used method for laparoscopic training. In this model of "see one, do one, teach one," feedback is directly provided during surgery in the OR, and the surgery is learned by the student through simple observation and, later, imitation of the actions of a skilled mentor. This model, which has many advantages and is undoubtedly ideal for specific procedures and at specific stages of the learning process, is currently limited by the fact that the reported learning curves (i.e., time required for reaching proficiency) are very long [22–26], that residents' working hours are shorter, and a great number of surgical procedures and skilled mentors are required.

The challenge is not to abolish this model, but to enhance its beneficial effects using validated strategies directed to shortening the learning curves and reducing complications [27–29]. Our data suggest that a future laparoscopist should first train in LPS (e.g., HEC), and only afterwards go for more advanced tasks (e.g., suturing, dissection, etc.). This strategy will permit clinical training in the OR to focus on specific surgical problems/conditions and not be jeopardized by insufficient knowledge and technical skills, allowing the surgeon to achieve maximal learning at minimal patient risk.

In conclusion, this study demonstrates the feasibility of training with a simple and affordable model suitable for monitoring the learning process. We confirmed that training improves laparoscopic skills and that many repetitions are required for proficiency. Our results strongly support the hypothesis that full acquisition of basic LPS, specifically HEC, facilitates the acquisition of more complex laparoscopic tasks, as well as the hypothesis that reaching proficiency in advanced tasks does not guarantee proficiency in basic tasks. Further studies are necessary to determine whether these two observations of skill acquisition are relevant to skill retention and if the second observation has any clinical significance. It also has to be evaluated the specific effect of other LPS (e.g., CN and BMC) and whether or not they have additive effects.

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Declaration of interest The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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