Changing the Learning Curve in Novice Laparoscopists: Incorporating Direct Visualization into the Simulation Training Program

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OBJECTIVE: A major challenge in laparoscopic surgery is the lack of depth perception. With the development and continued improvement of 3D video technology, the potential benefit of restoring 3D vision to laparoscopy has received substantial attention from the surgical community. Despite this, procedures conducted under 2D vision remain the standard of care, and trainees must become proficient in 2D laparoscopy. This study aims to determine whether incorporating 3D vision into a 2D laparoscopic simulation curriculum accelerates skill acquisition in novices.

DESIGN: Postgraduate year-1 surgical specialty residents ($n = 15$) at the Schulich School of Medicine and Dentistry, at Western University were randomized into 1 of 2 groups. The control group practiced the Fundamentals of Laparoscopic Surgery peg-transfer task to proficiency exclusively under standard 2D laparoscopy conditions. The experimental group first practiced peg transfer under 3D direct visualization, with direct visualization of the working field. Upon reaching proficiency, this group underwent a perceptual switch, changing to standard 2D laparoscopy conditions, and once again trained to proficiency.

RESULTS: Incorporating 3D direct visualization before training under standard 2D conditions significantly ($p <$ 0.0.5) reduced the total training time to proficiency by 10.9 minutes or 32.4%. There was no difference in total number of repetitions to proficiency. Data were also used to generate learning curves for each respective training protocol.

CONCLUSIONS: An adaptive learning approach, which incorporates 3D direct visualization into a 2D laparoscopic simulation curriculum, accelerates skill acquisition. This is in contrast to previous work, possibly owing to the proficiency-based methodology employed, and has implications for resource savings in surgical training. (J Surg Ed 74:30-36. Crown Copyright © 2016 Published by Elsevier Inc. on behalf of the Association of Program Directors in Surgery. All rights reserved.)

KEY WORDS: laparoscopy, 3D visualization, FLS, skill acquisition, adaptive training

COMPETENCIES: Practice-Based Learning and Improvement, Medical Knowledge

INTRODUCTION

Laparoscopic surgery offers patients a number of well-supported benefits including decreased pain, shortened hospital stay, and more rapid return to full activity.[1] It is one of the more significant surgical developments in recent history, with widespread adaptation and an ever-increasing utilization in many surgical fields.[2-4] The benefits, however, are accompanied by limitations to surgeon dexterity, including loss of depth perception, degraded image quality, misaligned eye-hand-target axis, magnified hand tremor, limited degrees of freedom, fulcrum effect, and unsteady camera.[5,6] These challenges in turn contribute to the long learning curves in training for advanced laparoscopic procedures.[7]

The potential benefit of restoring 3D vision and thereby depth perception to laparoscopic procedures was identified

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and first attempted in the early 1990s.[8,9] The first generation of 3D vision technology was of low image quality and many subjects found it to cause headaches, nausea, ocular fatigue, and dizziness.[10] Subsequent evaluations yielded results that varied in terms of demonstrating a benefit to 3D vision, and consequently the technology was not widely adopted.[10,11]

The advent of high-definition passive polarized 3D technology addressed many of these limitations and led to resurgent interest in the use of 3D vision in laparoscopy.[2,10-22] The new technology has prompted many authors to evaluate the benefit of 3D vision, specifically for novices in the early stages of their laparoscopic training.[10-18,21,22] The potential to use training time more efficiently and shorten laparoscopy's long learning curve is enticing in the current reduced resident work hour environment.[23,24]

Under conditions permitting minimal to no practice, novices demonstrated faster [10-14,16] and more accurate [11,13,14,16] completion of simulated laparoscopic tasks when using 3D compared to using 2D. In trials with low repetitions such as these, however, novice performance is significantly below proficiency standards or that of experienced laparoscopists, regardless of the visualization modality. To assess the value of 3D versus 2D in trainees, it might be more suitable to consider the entire path from naivety to proficiency.[18] This accumulation of experience and proficiency can be defined as the learning curve, where performance is plotted against experience. The goal of new training methodologies is to shift the learning curve and attain the same performance with less experience. Only a handful of studies have compared 3D with 2D in the context of learning curves in novice laparoscopists.[17,18,21,22]

Despite the growing interest in 3D technology, 2D remains the standard of care, and it is necessary for trainees to attain proficiency in 2D techniques. We propose to strategically incorporate 3D visualization into a 2D laparoscopic simulation curriculum. We hypothesize that this minor alteration in the early stages of laparoscopic training would shorten the learning curve, decreasing a novice's time and number of repetitions to proficiency (Fig. 1).

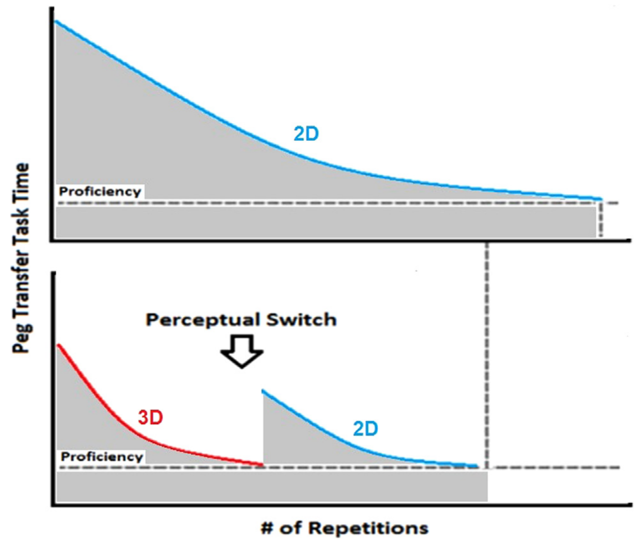

FIGURE 1. Illustration of the hypothesized effect of incorporating 3D visualization. "Perceptual switch" refers to a change between 3D and 2D visualization. Dashed vertical lines represent the difference in the total number of repetitions. The difference in total training time is the difference between shaded areas under the curves.

MATERIALS AND METHODS

Postgraduate year-1 surgical specialty residents ($n = 15$) at the Schulich School of Medicine and Dentistry, at Western University were recruited into the institutional review board approved study. All participants were already enrolled in the "Introduction to Surgery" course, a mandatory component of their training. The course includes an introduction to laparoscopic skills through a modified version of the Fundamentals of Laparoscopic Surgery (FLS) curriculum, and this study was incorporated into the training protocol of those who gave their informed consent. This occurred at the onset of the course's laparoscopy component, and there was no previous laparoscopy exposure as part of this course.

Each participant was asked to complete a demographic survey including a self-assessment of previous laparoscopy exposure. Participants lacking stereoscopic vision ($n = 1$), as assessed using the Graded Circles and Random Dot Stereo Butterfly Test Battery (Stereo Optical Company, Chicago, IL), were excluded from the study. All participants were trained on the correct procedure to complete the FLS peg-transfer task (Fig. 2A). In peg transfer, the operator consecutively lifts each ring with one grasper, transfers it to the other grasper, and places it on a peg on the alternate side of the board. Once all 6 rings have been transferred, this is repeated in the opposite direction. Peg transfer was selected as the exclusive task because, despite its perceived simplicity, previous studies had indicated that it actually required the most training time to reach proficiency and accounted for most of the total FLS training time.[18] After receiving instruction in the peg-transfer task, participants were randomized into 1 of 2 groups to practice. Participants completed training over 2 sessions, spaced 1 to 2 weeks apart, and each lasting 30 to 45 minutes, to achieve proficiency.

The control group practiced exclusively under 2D visualization, as in the traditional FLS curriculum (Fig. 2B). The task was performed using FLS protocol box trainers (VTI Medical, North Billerica, MA), accompanied by a standard 2D camera and a 32-in. display with 1080 pixel resolution. The completion time for each individual trial was recorded. The task was repeated consecutively and at the trainee's volition until the proficiency level, a trial of less than 60 seconds, was attained. The 60-second proficiency standard

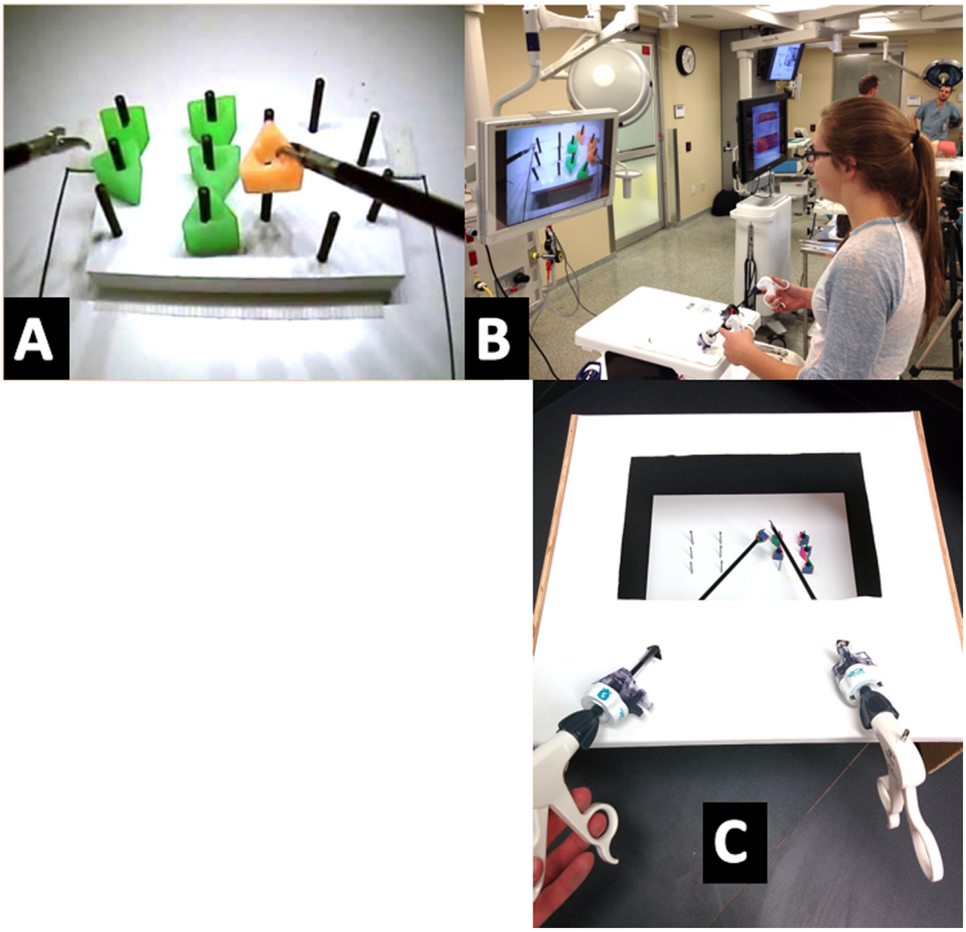

FIGURE 2. (A) FLS peg transfer, (B) standard 2D FLS box trainer arrangement, and (C) custom constructed open-top box trainers for 3D direct visualization.

was based on FLS scoring for the peg-transfer task, where errorless completion of the task in 63 seconds corresponds with a normalized score of 100.[25] In addition, 60 seconds was the standard for the course in which the participants were enrolled.

In contrast with the 2D exclusive group, the experimental group began their peg-transfer practice under 3D direct visualization, using custom constructed open-top box trainers (Fig. 2C). The completion time for each individual trial was recorded. The 60-second proficiency standard is easily achieved under 3D direct visualization and was therefore modified to 50 seconds, a target guided by what are considered expert proficiency scores.[26] Upon attaining a time of less than 50 seconds in 2 nonconsecutive trials, participants underwent a perceptual switch, wherein they continued to practice under 2D visualization identical to the first group. Practice was continued under the perceptual switch until a single trial of less than 60 seconds was attained, as in the first group.

The custom box trainer specifications were based upon the VTI Medical Trainer's specifications and are inexpensive and simple to implement. Laparoscopy tools and task apparatus were consistent across groups. Previous studies have made use of similar apparatus.[21,22] In addition to restoring depth perception, in 3D direct visualization the trainee also benefits from restored eye-hand-target axis and maximized image quality. The simplifications are justified in that they are a training tool and the ultimate goal remains to attain 2D proficiency.

DATA ANALYSIS

Both groups were evaluated for prior laparoscopic experience at the outset of the study. A between-group comparison of previous laparoscopy exposure was conducted using Fisher exact test. All comparisons of training data were made using one-tailed Welch *t*-tests, where each group's distribution was first validated to be sufficiently normal using the Shapiro-Wilk test of normality. Statistical significance was defined as $p < 0.05$ in all cases.

As participants stopped practicing upon reaching proficiency, data sets for each participant are uneven in length. Shorter data sets were fit with a power law, as is

TABLE 1. Participant Demographic Information

Condition	2D Exclusive, $n = 8$	Perceptual Switch, $n = 7$
Sex (male/female)	3/5	4/3
Mean age (years) (range)	27.1 (23-31)	26.7 (25-29)
Dexterity (right/left)	7/1	5/2
Previous FLS exposure		
None	4	2
Casual/limited	2	4
Informal practice	2	1
Formal training	0	0

characteristic of learning curves[27] and extrapolated to obtain an equal number of data points for each participant. This was done to construct average learning curves for illustrative purpose, but points incorporating extrapolated data were not used in any statistical comparisons.

RESULTS

The results of the demographic survey are summarized in Table 1. Between-group comparison of previous laparoscopy exposure suggests that there was no statistically significant difference between the 2 groups at the outset of the study ($p = 0.54$, Fisher exact test).

The mean total training time to proficiency (mean ± standard deviation) was 33.5 ± 14.5 minutes for the 2D exclusive group and 22.6 ± 7.1 minutes for the 3D direct to 2D perceptual switch group. This represents a statistically significant ($p < 0.05$) reduction of 32.4%. No difference was demonstrated with respect to total number of repetitions to proficiency. These results are summarized in Table 2.

The average learning curves for the 2D exclusive group and the perceptual switch groups are illustrated in Figure 3. Points incorporating extrapolated data are without error bars. Trial time increased for all participants in the perceptual switch group after switching from 3D direct to 2D visualization. Upon reaching the 3D direct proficiency standard of 50 seconds, the mean trial time for the initial 2D trial after the perceptual switch was 90.9 ± 11.7 seconds.

The 2D component of the perceptual switch group's training was compared against the 2D exclusive training, as summarized in Table 3. The initial 2D trial after the perceptual switch is compared against the initial trial of 2D exclusive training as well as against the trial occurring after 500 seconds of 2D exclusive training (Fig. 4).

DISCUSSION

The opportunity to practice the peg-transfer task under 3D direct visualization significantly reduced the total training time required to achieve 2D proficiency but not the total number of repetitions required (Table 2). The nature of the reduction is further illustrated in Figure 4. The area under each learning curve represents total training time. The shaded region, therefore, suggests that most of the 10.9 minutes or 32.4% reduction in total training time (Table 2) can be attributed to the period of 3D direct practice.

Data from this approach illustrate that initial trials of 2D exclusive training were associated with a dramatic improvement in speed (Fig. 3A). By comparison, Fig. 3B indicates that under 3D direct visualization participants start much closer to proficiency. Following the perceptual switch, trial speeds decreased relative to direct visualization, but not to the same degree as the initial 2D exclusive trials (Table 3).

The shift in the learning curve was further validated by comparing trial times after the perceptual switch to trial times after an equivalent total amount of 2D exclusive training (Table 3). The perceptual switch occurred on average at 505.3 seconds of total training time. Therefore, the initial 2D trial after the perceptual switch is compared against the fourth 2D exclusive trial, which occurred after an average of 500.5 seconds total training time.

The 2D exclusive group demonstrated higher variability in their initial trial times, with participant times ranging from 1.75 to 6 minutes. This degree of variability was not

TABLE 2. Difference Between 2D Exclusive and 3D Direct to 2D Perceptual Switch Groups in Total Training Time and Total Number of Repetitions

	2D Exclusive, $n = 8$ Mean (SD)	Perceptual Switch, $n = 7$ Mean (SD)	p
3D Total training time (min)	—	8.4 (3.1)	
2D Total training time (min)	33.5 (14.5)	14.2 (5.0)	
Total training time	**33.5 (14.5)**	**22.6 (7.1)**	**0.045**
3D Repetitions	—	8.4 (2.9)	
2D Repetitions	20.5 (7.8)	11.4 (3.7)	
Total repetitions	**20.5 (7.8)**	**19.9 (5.8)**	**0.429**

p Values generated using one-tailed Welch *t*-test. SD, standard deviation.

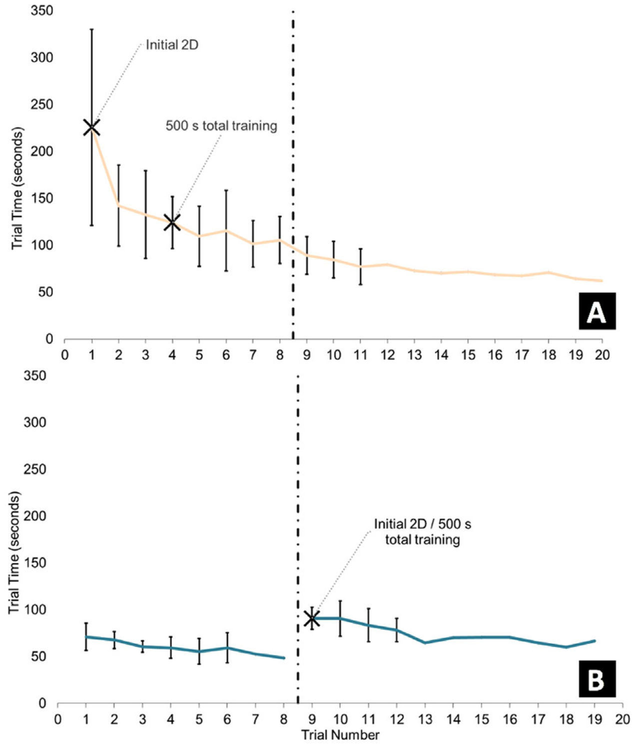

FIGURE 3. (A) Average learning curve for the 2D exclusive training group. Error bars represent standard deviation for points with complete data sets. (B) Average learning curve for the 3D to 2D perceptual switch training group. Errors bars represent standard deviation for points with complete data sets. Dashed line marks the perceptual switch.

observed in the perceptual switch group, neither under 3D direct nor under 2D visualization (Table 3). Within each group, variability can be attributed to participant differences in previous laparoscopy exposure as well as innate aptitude for laparoscopy, whereas the reduction in variability from 2D exclusive to perceptual switch is a potential effect of training methodology.

Adaptive training, that is adjusting a task's difficulty as incremental levels of skill are achieved, is common in teaching complex perceptual-motor skills. The theory suggests that an adaptive approach enhances skill acquisition because modulating difficulty in response to skill level maintains an optimal learning state.[28] Loss of 3D vision, misalignment of the eye-hand-target axis, and degradation of image quality have been demonstrated to be the most significant challenges associated with laparoscopy.[5,6] Direct visualization alleviates these challenges, allowing trainees to focus on overcoming other difficulties, such as the limited degrees of freedom or the fulcrum effect, as well as acquainting themselves with the given task. The most significant challenges are reintroduced only once the simplified task has been mastered in a manner of adaptive training.

Perkins et al.[21] and Dubrowski et al.[22] have previously investigated incorporating 3D direct visualization into adaptive strategies for training laparoscopic skills. Unlike the results of the current study, neither group found improved skill acquisition when training under 3D direct visualization before standard 2D visualization. The major difference between these previous investigations and the current one is a proficiency-based training model. In our study, participants were trained under each condition for only as long as it took to reach predetermined proficiency standards. Conversely, training for a fixed number of repetitions or fixed total time can mismatch a trainee's learning needs versus learning stimulus. For example, under fixed quantities of training, a trainee might be required to continue practicing under 3D direct visualization beyond the point where this difficulty level continues to provide learning benefit. This in turn can mask a benefit to the adaptive learning approach, as the training stimulus might be correct while the quantity of exposure might not. Proficiency-based training has received much attention in the context of surgical training, and a number of curricula are moving in this direction.[29-31]

Stefanidis et al. also investigated proficiency-based adaptive training of laparoscopic skills, though not in the context of visualization modality. They hypothesized that completing a basic training protocol before practicing the FLS suturing task would enhance skill acquisition. They demonstrated that the number of repetitions to achieve proficiency was reduced when incorporating basic training, which in turn was estimated to save 148 USD per trainee because of reduced consumption of materials. However, they did not find that overall training time was reduced.[32] As the peg-transfer task does not involve any consumables, it is difficult to establish the cost saving value of our approach. Our approach is inexpensive to implement, especially when considering the $125,000 cost of a 3D-

TABLE 3. Comparison of Mean Trial Time at Points Along the 2D Exclusive Learning Curve and the Perceptual Switch Learning Curve

	Point	2D Exclusive* Mean (SD)	Perceptual Switch† Mean (SD)	p
Trial time (s)	Initial 2D	225.6 (104.2)	90.9 (11.7)	0.004
	500 s total training	124.1 (27.6)	90.9 (11.7)	0.006

p Values generated using one-tailed Welch t-test. SD, standard deviation.
*Points marked on Figure 3A.
†Point marked on Figure 3B.

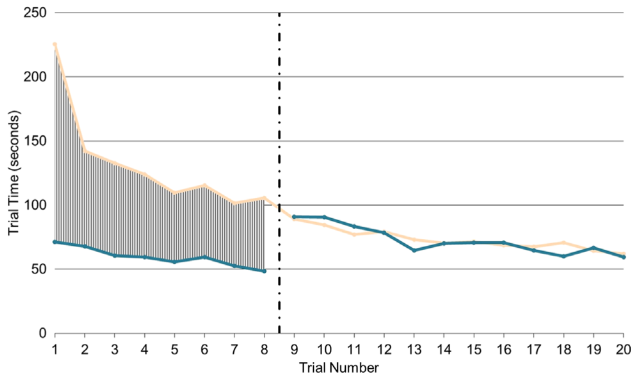

FIGURE 4. Superimposed 2D exclusive and perceptual switch learning curves. The difference in area under the curve, the shaded region, represents a difference in total training time. Dashed line marks the perceptual switch.

capable laparoscopy system,[33] and demonstrated to accelerate skill acquisition. There is a potential for cost saving benefit, when applied to more complex tasks involving consumables, which requires further investigation.

One limitation to this study is participant differences in innate aptitude for laparoscopy. Though it was demonstrated that groups were equal with regard to previous laparoscopy exposure, aside from randomization, it is challenging to control for natural talent. Secondly, this study was incorporated into a class environment, which may have posed a distraction to some individuals' training. For example, training was interrupted so that other FLS tasks could be demonstrated, though it is important to note that participants did not ever practice other FLS task while completing this study. Finally, the current study could not assess the longevity of the effects of direct visualization on future performance, as trainees could not be ethically asked to stop training during the dedicated curriculum of their surgical training.

This study demonstrated an apparent shift in the learning curve and a significant improvement in total training time when incorporating 3D direct visualization. This contrasts previous work,[21,22] and the subject requires further investigation. Future studies would benefit from a larger sample size of homogenously laparoscopy-naïve participants. Future directions might investigate applying 3D direct visualization in training laparoscopic tasks that are more complicated than peg transfer and evaluating for cost saving benefit. We hypothesize that as task complexity increases, participants may further benefit from an adaptive learning approach with initial practice under the simplified conditions of 3D direct visualization.

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