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Review

Can 3D Vision Improve Laparoscopic Performance in Box Simulation Training when Compared to Conventional 2D Vision?

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Abstract

Introduction: Three-dimensional (3D) imaging systems have been introduced in laparoscopic surgery to facilitate binocular vision and dexterity to improve surgical performance and safety. Several studies have shown the benefits of 3D imaging in laparoscopy, but until now only a few studies have assessed the outcome by using objective variables. Box trainers are affordable alternatives to virtual laparoscopic surgical training, and the possibility of using real surgical instruments makes them more realistic to use. However, the data and feedback by a virtual simulator have not, until now, been able to assess. Simball Box®, equipped with G-coder sensors®, registers the instrument movements during training and gives the same feedback like a virtual simulator.

Aim: The aim of this study was to objectively evaluate the laparoscopic performance in 3D compared to conventional 2D vision by using a box simulation trainer.

Materials and methods: Thirty surgeons, residents and consultants, participated in the study. Eighteen had no, or minimal, laparoscopic experience (novices) whereas 12 were experts. They all performed three standard box training exercises (rope race, precision cutting, and basic suturing) in Simball Box. The participants were randomized and started with either 3D HD or traditional 2D HD cameras. The exercises were instructed and supervised. All instrument movements were registered. Variations in time, linear distance, average speed, and motion smoothness were analyzed.

Results: The parameters time, distance, speed, and motion smoothness were significantly better when the 3D camera was used.

Conclusion: All individuals of both subgroups achieved significantly higher speed and better motion smoothness when using 3D.

Keywords

basic surgical skills, box training, 3D vision, 2D vision, laparoscopy, surgical simulation

INTRODUCTION

An increasing number of operations are performed with the laparoscopic approach as golden standard. Many technological innovations and improvements have been introduced in the area of laparoscopy, which aims to improve ergonomics, performance, and efficiency. Even though laparoscopy with three-dimensional (3D) imaging has been available for more than 20 years[1], it has not, until today, been able to replace conventional two-dimensional (2D) imaging, which is still predominant in the operating room (OR). In earlier studies, the participants viewed the 3D system as being "less clear" and "darker".[1] With newly designed, high-definition (HD), stereoscopic 3D visualization systems, that barrier is overcome.[2] By providing an extra dimension, 3D offers depth and space perception, thereby optimizing eye-hand coordination as well as improving binocular vision and dexterity. It is said to improve accuracy and efficiency, increase precision, improve safety, lower operating times, and shorten learning curves.[3] Several studies describing the beneficial effects of 3D compared to 2D imaging on surgical outcomes have been published in the last two decades.[4-7]

Until today, most of these studies have focused on evaluating subjective factors such as errors and user experience and lacked, besides time, the tools for objectively assessing laparoscopic performance.[8] The vast majority of the studies that showed superiority of 3D vs. 2D visualization also used experimental surgical models.[9]

The technical skills and high standards required for safe laparoscopic surgery have led to the introduction of surgical simulators to prepare surgeons before they perform the procedure for the first time. To evaluate the performance of young surgeons, the present laparoscopic simulator systems can register the movements of the instruments during an exercise and provide instant feedback to the trainee. However, since virtual reality (VR) is expensive, the variation and complexity necessary to satisfy the need for training are usually not fully met.

AIM

The aim of this study was to objectively evaluate the effect of 3D imaging versus 2D on laparoscopic performance in a box simulator using objective data from instrument movements.

MATERIALS AND METHODS

The study was performed at the Department of Surgery, Mora Hospital, Mora, Sweden. The participants completed a research protocol stating their age, sex, dominant hand, and years in surgery, if they regularly played video games, and if they were validated in LapSim®.

Participants

Thirty members of the surgical clinic participated voluntarily. The participants were categorized as experienced or non-experienced. The experienced had been performing laparoscopic surgery independently for at least two years, and the non-experienced had non-independent and minimal experience. In the experienced group were 12 consultants, all performing laparoscopic surgery on a regular basis, and in the non-experienced group, there were 18 trainees and residents. No considerations were taken to the dominant hand more than that it was registered. The participant's history of using video games and their "driving license" in VR laparoscopic simulation was registered. The surgical department at Mora hospital hires a VR laparoscopic simulator (LapSim) where all residents are evaluated and get their "driving license" by completing an exercise program. It is a compulsory step before starting laparoscopic operations.

Compliance with ethical standards

All the test subjects participated on a voluntary basis and gave informal consent. All the procedures performed in the studies were in accordance with the ethical standards of the participating institution and the ethical committee of the hospital as well as with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All authors declare no conflict of interest.

Exercises

All participants were to complete three standardized exercises (rope race, precision cutting, and basic suturing). The exercises chosen are all part of the Basic Surgical Skills course in Sweden, which is derived from the Royal College of Surgeons. The participants were given standardized instructions and a demonstration before each exercise. Every exercise was repeated five times for each imaging system. After completing the three exercises, five times each, they were then asked to come back to repeat the same procedure with the other system after a minimum of two days had passed. The participants were randomized in total and in the subgroups to start with either 3D or 2D.

Rope race

A lacelike rope is to be thread through eight loops. Using two curved graspers, the participants thread the lace through the loops starting from left to right (**Fig. 1**). The time and movement registration start with the rope in the middle of the model and stops when the rope's end passes through the last loop. To pass the rope through the loops effectively, interaction of both hands is required.

Precision cutting

In this exercise, the participants were asked to cut a circle on a latex membrane, keeping their cutting line between the circle borders (**Fig. 2**). Registration starts with the instruments, grasper and a pair of scissors, not in contact with the membrane and ends when the circle is dissected. The fine dissection in this exercise involves manual dexterity and deep perception to keep the cutting line within the borders.

Basic suturing

A single suture was to be tied in a rubber wound model (**Fig. 3**). The aim was to place the suture and tie a double-single-single knot using two needle holders and a pre-cut 13 cm long monofilament suture on a V20 needle. Registration starts with the needle in position on the right instrument and ends with the third knot tightened. It was compulsory to shift the needle between the instruments for every knot tying. Due to the difficulty of locating the thin thread and needle in space, depth perception is highly important in this exercise.

Materials

The box trainer system used, Simball Box®, is equipped with G-Coder Sensors® port system and is also used in the LapSim's VR laparoscopic simulator (Surgical Science Sweden AB, Gothenburg, Sweden) to register the instrument movements during every exercise. The registered data are assessed in the ports. A unique pattern is recorded, and highly detailed data of the movement of the instrument were given. The box has an installed full-HD camera fixed between the instrument ports.

Both cameras used were HD cameras. The 3D camera system used was Einstein 2.0 by Aesculap, BBraun® incorporating two parallel rod lenses. The system was equipped with a 32-inch, full-HD resolution (1920×1080 pixels) transmitted to polarization monitors, thereby reducing the vertical resolution to half (1920×540) due to a line-by-line assignment of the right and left-eye image. For the 3D effect, polarized eyeglasses were used. In the 3D system, two cameras in the head capture the image from different viewpoints. The picture is processed and displayed onto a TV screen. The viewer needs 3D glasses to create the illusion of spatial depth.[10] The same box was used for both camera systems. The 2D camera (G-coder Systems AB, Västra Frölunda, Sweden) was displayed on a 19-inch screen (EIZO, Japan). The box and the ports allowed us to use real laparoscopic instruments similar to those used at our clinic. The Einstein Vision 2.0 camera system was connected to the box and fixed with a specially designed arm so that the camera was positioned at the same angle and position as the conventional 2D camera. The light conditions were equal, but the screens varied in size. The larger 3D screen was therefore placed further away from the participant.

Measurements

With the G-coder sensor system, all instrument movements were recorded. The special technology in the ports records all motions of the instruments with very high accuracy. The variables given were time (s), the instrument tips linear distance (cm) in 3D space (total, x, y, z), and angular distance and rotation (yaw, pitch, roll). From that data, the average speed of the tip (cm/s), average acceleration (mm/s^2), and motion smoothness (μm/s^3) were calculated.

Acceleration represents the derivative of the velocity of the tip with respect to time and motion.

Motion smoothness, also known as the jerk, is the derivative of acceleration of the tip with respect to time, and it represents the rate of change of acceleration.

Statistical analysis

The non-parametric test (Wilcoxon Signed Rank test) was used to compare the median values of the linear distance for each hand, as well as the total, average speed, motion smoothness, and time in the 3D and 2D sessions. A $p < 0.05$ was considered to be significant and <0.01 as strongly significant.

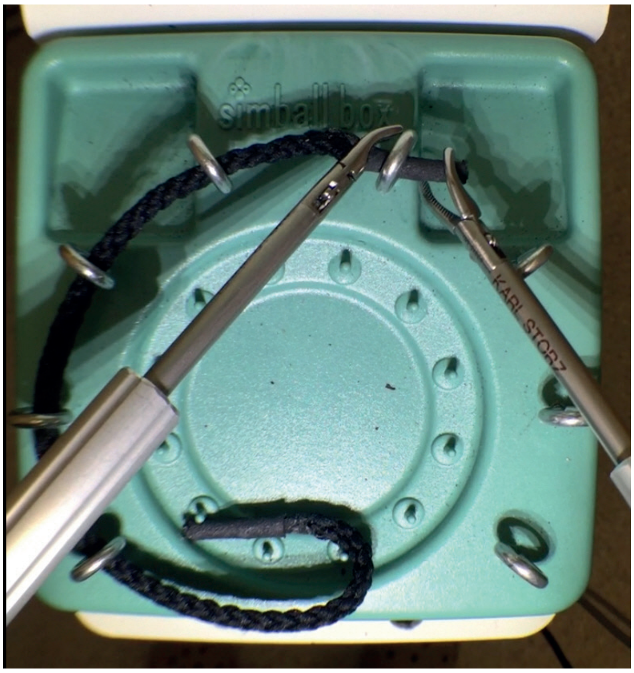

Figure 1. Rope race.

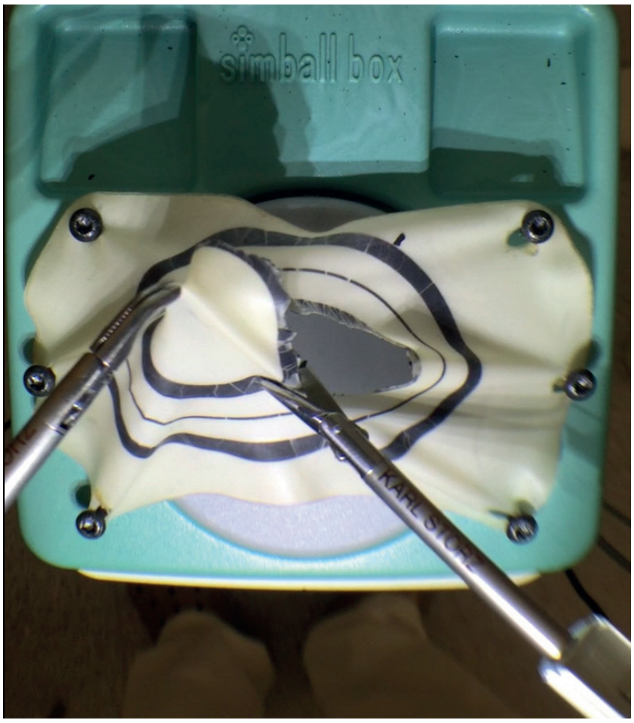

Figure 2. Precision cutting.

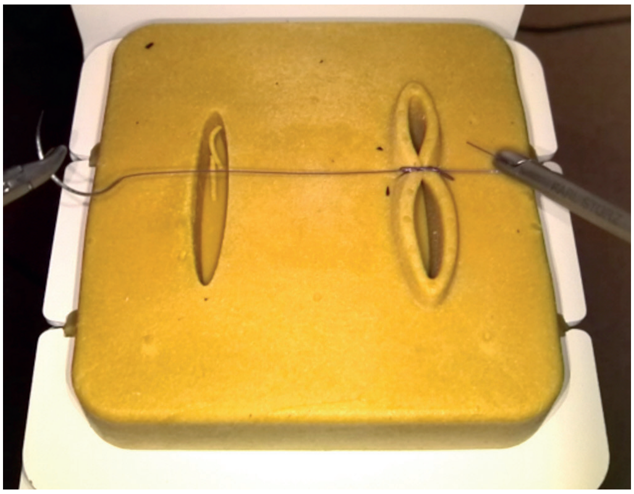

Figure 3. Basic suturing.

RESULTS

Demographic data

The median age was 29 (range 25-34) years old in the non-experienced group, 46 (34-62) years in the experienced group, and 35 (25-62) years overall. The average surgical and laparoscopic experience in the experienced group was 17 (4-31) and 14 (3-23) years, respectively. The non-experienced group had surgical experience of two months, or less, and no laparoscopic experience. Only two participants were left-handed, one in each group (**Table 1**).

Rope race

The performance, using 3D vision, was significantly better compared to 2D in all parameters. Both subgroups performed faster and smoother with 3D. The non-experienced group benefits with 3D on the linear distance of the right hand, and in total as well as time, to complete the exercise (**Table 2**).

Precision cutting

In the second exercise, a significantly better performance regarding motion smoothness was observed in total and in the subgroups alone, using 3D vision. The experienced group also performed faster with 3D. The average time was significantly shorter overall (**Table 3**).

Basic suturing

In the last and most challenging exercise of the study, strong correlations (p <0.01) between 3D imaging and performance were observed in all parameters, except for the linear distance of the right hand (p <0.05). The non-experienced group performed significantly better with 3D in all parameters (**Table 4**).

Motion smoothness

The lack of experience in the non-experienced group can easily be seen in their more scattered plots while the experienced group has more focused plots, and a distinct improvement is seen when the 3D camera is used (**Fig. 4**). Motion smoothness is proven significant even when time is not.

DISCUSSION

In order to extract depth information in conventional 2D displays, the surgeon must rely on indirect visual cues such as shadows, textures and relative color differences. In contrast, in modern 3D laparoscopy, images are viewed via passive polarization in which the viewer wears lightweight glasses that polarize horizontal rows of pixels on the display, with alternate pixel rows corresponding to the right- and left-eye images.[11]

The available literature comparing 2D vs. 3D laparoscopic visualization show conflicting data regarding a potential benefit of 3D on surgical performance. This may be attributed to that earlier studies used old 3D technologies that were not able to show significant differences in surgical performance.[4-7,12] However, current studies using modern 3D imaging suggest that it improves performance as measured by the number of errors committed and the time needed to accomplish a task. Experts seem to gain similarly in precision and time needed as compared to novices. In addition, stereoscopic vision seems to improve learning curves in novices.[12] Additionally, it is suggested that 3D laparoscopy in small spaces is associated with a significant shorter operating time and therefore may facilitate minimal invasive surgery in neonates and infants.[13] It is worthwhile to note that most of these studies are using an experimental surgical simulation model.[9,14,15] In a recent review, until April 2015, only three clinical trials comparing 2D and 3D were carried out in a clinical setting while 28 studies used a simulated setting.[8] Regarding experimental studies most of them included relatively small numbers of subjects and/or of phantom tasks while some included non-validated tasks.[12]

However, a study based on a large number of participants (50 novices but eight experts only) who were randomly assigned to perform five standardized tasks adopted from the Fundamentals of Laparoscopic Surgery (FLS) curriculum in either a 2D or 3D laparoscopy simulator confirmed earlier data.[12] Participants felt more confident and comfortable when using a 3D laparoscopic system. In another crossover study, 30 novices without any previous laparoscopic surgery experience were divided into matched groups on five standardized laparoscopic visuospatial tests. The mean time of tasks completion was faster in the 3D group as compared to the 2D group. The 3D group showed a lower rate of errors, but this only reached statistical significance in two of the five laparoscopic tasks. Additionally, those who had trained on 3D simulators arrived at proficiency levels sooner than the 2D group.[2]

However, the question still remains whether these findings translate into faster and safer operations in a clinical setting. Thus, in the clinical setting the group of Currò et al. has recently published three case control studies comparing 3D vs. 2D laparoscopic procedures for bariatric surgery[9], right hemicolectomy[16], and cholecystectomy[17]. Additionally, Agrusa et al. reported thirteen 3D laparoscopic adrenalectomies and compared the outcomes to 26 laparoscopic ones made with 2D which served as the control group.[18]

All the aforementioned studies conclude that 3D vision systems do not influence the operative time of the laparoscopic procedure when the surgeon is experienced in 2D laparoscopy, although better depth perception and subjective less physical strain can be achieved with the 3D system

Table 1. Demographic data

	n	Age median (range) years	Sex M:F	Dominant hand R:L	Experience Median (range) years		Computer Games	Lap-Sim license	Time 2D‹–›3D Median (range) days
					Surgery	Lap			
Non-experienced	18	29 (25-34)	12:6	17:1	0 (0-2)	0 (0-1)	7	1	31 (3-91)
Experienced	12	46 (34-62)	7:5	11:1	17 (4-35)	14 (3-23)	3	5	22 (2-95)
Total	30	35 (25-62)	19:11	28:2	7 (0-35)	6 (0-23)	10	6	27 (2-95)

Table 2. Rope race

	Non-experienced		Experienced		Total	
	2D	3D	2D	3D	2D	3D
Linear distance, left (cm)	226.01	183.17	163.21	157.63	195.47	176.38*
Linear distance, right (cm)	235.78	181.78*	169.59	149.64	192.12	171.51*
Linear distance, total (cm)	459.51	387.10*	329.66	316.02	483.50	356.49*
Speed (cm/s)	1.63	1.97*	2.07	2.20*	1.85	2.07**
Motion smoothness (mm/s^3)	60.07	31.82**	70.48	31.71**	65.80	31.82**
Time (s)	139.00	101.80**	75.20	70.90	114.20	84.20**

* $p<0.05$; ** $p<0.01$

Table 3. Precision cutting

	Non-experienced		Experienced		Total	
	2D	3D	2D	3D	2D	3D
Linear distance, left (cm)	226.01	183.17	163.21	157.63	195.47	176.38*
Linear distance, right (cm)	235.78	181.78*	169.59	149.64	192.12	171.51*
Linear distance, total (cm)	459.51	387.10*	329.66	316.02	483.50	356.49*
Speed (cm/s)	1.63	1.97*	2.07	2.20*	1.85	2.07**
Motion smoothness (mm/s^3)	60.07	31.82**	70.48	31.71**	65.80	31.82**
Time (s)	139.00	101.80**	75.20	70.90	114.20	84.20**

* $p<0.05$; ** $p<0.01$

Table 4. Basic Suturing

	Non-experienced		Experienced		Total	
	2D	**3D**	**2D**	**3D**	**2D**	**3D**
Linear Distance, left (cm)	282.99	224.80*	181.54	151.88	235.09	205.45**
Linear Distance, right (cm)	260.91	200.47*	194.43	175.12	234.53	193.09*
Linear Distance, total (cm)	532.01	419.92*	386.59	331.14	473.61	376.52**
Speed (cm/s)	1.94	2.27**	2.45	2.90**	2.20	2.64**
Motion Smoothness (mm/s^3)	72.12	35.53*	78.23	36.24**	74.75	36.21**
Time (s)	133.30	87.90**	78.20	57.70**	106.40	77.10**

* $p < 0.05$; ** $p < 0.01$

as compared to 2D vision. On the contrary, it seems that novices achieve shorter learning curves and faster operative time when they use 3D.

The present study shows objectively that 3D imaging improves laparoscopic performance and accuracy. Both subgroups favour 3D, with the participants performing the exercises faster and with shorter movements.

Even though the speed of the instruments in 3D was higher, the “tip-to-target” movements were more precise as motion smoothness was lower. The motion smoothness variable, which describes the changes of acceleration with time, was shown to be significantly lower in 3D as compared to 2D in all three exercises and in both subgroups (**Tables 2-4**). Low motion smoothness indicates less correction in movements. More precise movements in the exercise with 3D vision could indicate that an extra dimension helps both the eyes and the brain, resulting in better surgical technique. That hopefully generates a safer, faster operation and a shorter learning curve.

Smith et al.[19] compared 3D versus the 2D mode of 20 novice surgeons in a box trainer with similar to our setting exercises. He also found significant less errors, as well as significant improvement in the mean time taken to complete all four tasks when using the 3D system. Some time later the same group repeated the same protocol with 20 experts and found 62% reduction in the median number of errors and an enhancement of median motion smoothness, and a 15% decrease in grasper frequency with the 3D versus 2D vision.[20]

Our study’s results regarding motion smoothness differ from Smith R et al.[20], who showed a higher value in motion smoothness using 3D. In our study, the lower value of motion smoothness is believed to be explained by the more accurate “tip-to-target” movements. Theoretically, the extra dimension helps the user to stop the tip of the instrument closer to the target with less correcting movements, suggesting that the brain gets more information from 3D, resulting in more controlled movements with hands and instruments. This theoretical approach is further enhanced from the work of Sakata et al.[11] who showed that higher stereo acuity allows better performance. They also found a higher precision of depth judgment, technical performance and perceived workload by using 3D laparoscopic displays across different viewing distances.[11]

The study shows a significantly better performance of many of the assessed parameters with 3D when compared to 2D, both overall and within the subgroups, although the groups are small in number. Further studies with larger groups need to be done to confirm our results.

The subgroup with no experience had significant shorter movements with the right hand in rope race and basic suturing, while their left-hand movements were only significantly shorter in the most challenging exercise i.e. 3D basic suturing. This finding could indicate that, for non-experienced users, the dominant right hand was used more as the dominant exercise hand.

Precision cutting is hard to standardize. It hones tissue-handling and fine dissection skills, but the stretching of the rubber membrane, and differences in the accuracy of cutting, gave the participants different preconditions and results. Some participants did the exercise as quickly as possible, while others did it as neatly as possible, which could influence the data and final results. Motion smoothness is still significant. Further studies, comparing the subject results and performance, must be undertaken.

It is quite possible that the feeling of something new and futuristic enhances greater performances in 3D. This would then be in line with what has already been proven.

With the possibility of being able to evaluate and compare performances, other techniques could be compared against each other. For instance, robot assisted surgery (RAS) is introduced as a modern technique, compared to traditional open and 2D laparoscopic surgery. Early studies using the 2D Zeus robot showed that robotic surgery without 3D did not have much benefit over traditional laparoscopy. However, a recent cross evaluation study has shown that for novices, there is a significant benefit of the daVinci S Robot over 3D straight-stick laparoscopy for laboratory

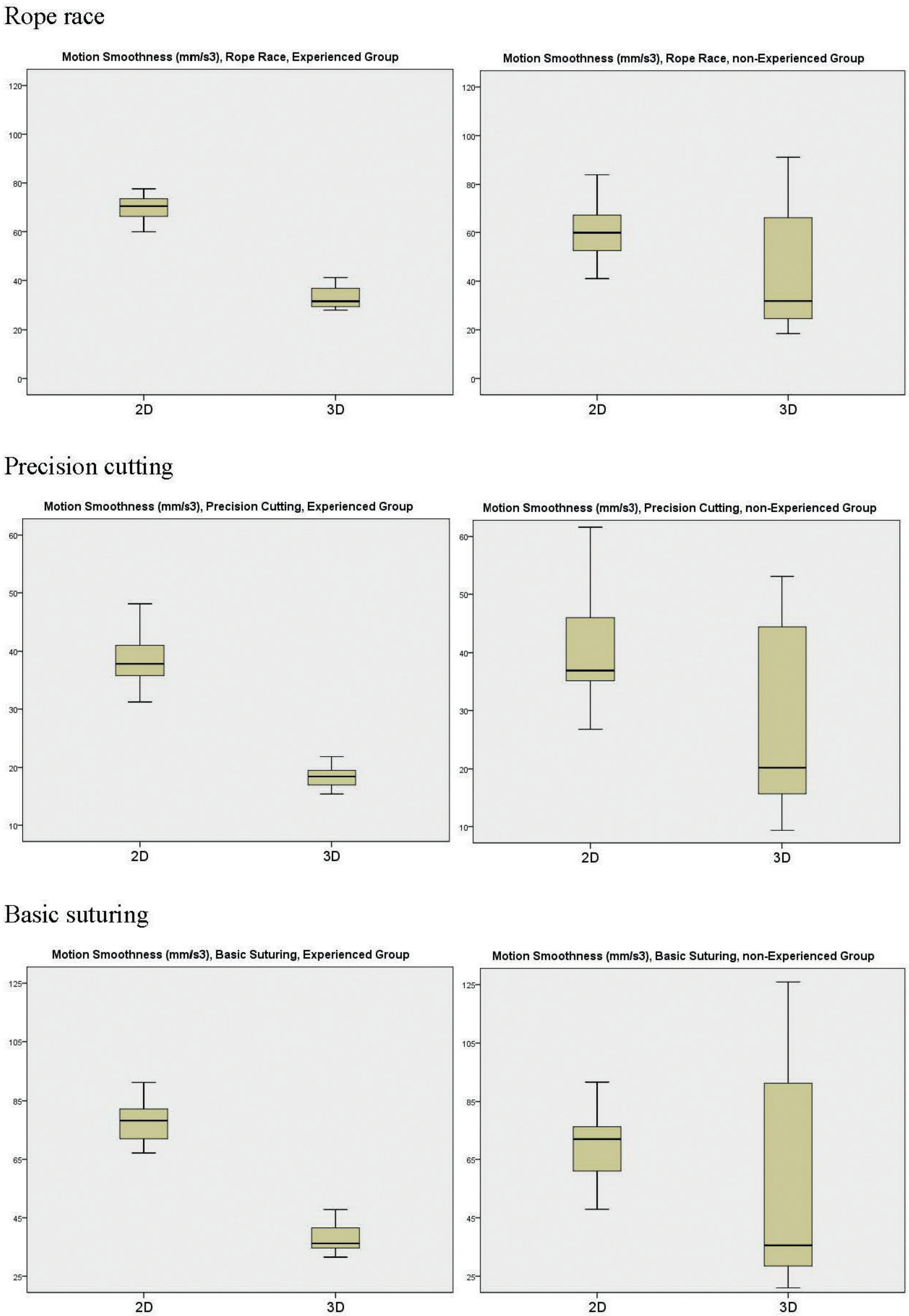

Figure 4. Motion smoothness boxplot diagrams of experienced and non-experienced groups in rope race, precision cutting, and basic suturing

tasks, with reduced error rates and quicker task performance times.[21]

Due to the low number of repetitions of every exercise in this study, we were not able to draw and compare learning curves with 3D and 2D in simulation training. Further studies on learning curves in box training should be able to demonstrate any differences in learning. This can, in the future, encourage the implementation of 3D imaging even in training modules.

Moreover, further studies are necessary to address whether novice surgeons could benefit from a reduced learning curve using 3D visualization and to verify with large cohorts if 3D vision can reduce perioperative complications.

CONCLUSIONS

In conclusion, our study, despite its small size, clearly shows that 3D imaging enhances laparoscopic performance in box trainers, no matter the experience. With the increasing role of laparoscopy in surgery, our study indicates that the implementation of 3D vision may increase performance in the OR. New generations of 3D imaging systems will certainly gain advantages over 2D in laparoscopic surgery. Even experienced surgeons would benefit by adding an extra dimension.

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Может ли 3D-визуализация улучшить лапароскопические эффективность при симуляционном обучении с помощью имитатора бокса-тренажёра по сравнению с обычной 2D-визуализацией?

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Абстракт

Введение: В лапароскопической хирургии были внедрены трёхмерные (3D) системы визуализации, чтобы облегчить бинокулярное зрение и ловкость, чтобы повысить эффективность и безопасность хирургического вмешательства. Несколько исследований продемонстрировали преимущества трёхмерной визуализации в лапароскопии, но до настоящего времени только несколько исследований оценивали результаты с использованием объективных переменных. Лапароскопические бокс-тренажёры являются доступной альтернативой виртуальному лапароскопическому хирургическому обучению, а возможность использовать настоящие хирургические инструменты делает их более реалистичными в тренировках. Однако данные и отзывы от виртуального симулятора до сих пор не оценивались. Simball Box®, оснащённый датчиками G-coder®, регистрирует движение инструмента во время тренировки и выдаёт ту же обратную связь, что и виртуальный симулятор.

Цель: Цель этого исследования состояла в том, чтобы объективно оценить лапароскопические характеристики при 3D по сравнению с традиционной 2D-визуализацией с использованием лапароскопических бокс-тренажёров.

Материалы и методы: В исследовании приняли участие 30 хирургов, специалистов и консультантов. 18 человек не имели или имели минимальный опыт лапароскопии (новички), а 12 были экспертами. Все они выполнили три стандартных упражнения на бокс-тренажёре Box Simball Box®. Участники были выбраны случайным образом и начали с 3D HD или традиционных 2D HD камер. Были проведены инструктаж и наблюдения упражнений. Все движения инструмента были записаны. Были проанализированы вариации во времени, линейном расстоянии, средней скорости и плавности движений.

Результаты: Время, расстояние, скорость и плавность были значительно лучше при использовании 3D-камеры.

Выводы: Все лица в обеих подгруппах достигли значительно более высокой скорости и лучшей плавности движений при использовании 3D.

Ключевые слова

3D-визуализация, 2D-визуализация, бокс-тренажёр, лапароскопия, основные хирургические навыки, хирургическая симуляция