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Original Research

Acquiring basic and advanced laparoscopic skills in novices using two-dimensional (2D), three-dimensional (3D) and ultra-high definition (4K) vision systems: A randomized control study

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ABSTRACT

Aims: To compare the performance of novices in laparoscopic peg transfer and intra-corporeal suturing tasks in two-dimensional (2D), three-dimensional (3D) and ultra-high definition (4K) vision systems.

Methods: Twenty-four novices were randomly assigned to 2D, 3D and 4K groups, eight in each group. All participants performed the two tasks on a box trainer until reaching proficiency. Their performance was assessed based on completion time, number of errors and number of repetitions using the validated FLS proficiency criteria.

Results: Eight candidates in each group completed the training curriculum. The mean performance time (in minutes) for the 2D group was 558.3, which was more than that of the 3D and 4K groups of 316.7 and 310.4 min respectively ($P < 0.0001$). The mean number of repetitions was lower for the 3D and 4K groups versus the 2D group: 125.9 and 127.4 respectively versus 152.1 ($P < 0.0001$). The mean number of errors was lower for the 4K group versus the 3D and 2D groups: 1.2 versus 26.1 and 50.2 respectively ($P < 0.0001$).

Conclusion: The 4K vision system improved accuracy in acquiring laparoscopic skills for novices in complex tasks, which was shown in significant reduction in number of errors compared to the 3D and the 2D vision systems. The 3D and the 4K vision systems significantly improved speed and accuracy when compared to the 2D vision system based on shorter performance time, fewer errors and lesser number of repetitions.

1. Introduction

Laparoscopic surgery has shown benefits for simple and relatively complex surgical procedures compared with open surgery [1]. These advantages resulted in aiming to perform more complex laparoscopic surgical procedures. However, performing advanced laparoscopic procedures remains challenging due to technical limitations, in addition to other hurdles such as the fulcrum effect, haptic feedback and instrument design [2,3,4]. Limited vision due to reliance on laparoscopic cameras has been considered a major disadvantage of laparoscopy [5]. Major advances in videoscopy focused on improving image quality leading to high-resolution images [6].

The 3D vision system was thought of as a replacement to the 2D vision system to overcome the lack of depth perception and to improve laparoscopic performance especially in complex tasks. Many studies [6,7,8,9] have shown that 3D vision systems have many benefits but until now it is not widely used in laparoscopic surgery [10]. 3D vision systems are also associated with some limitations as the high cost, the need to wear special kind of eyeglasses [11], and the reported side effects associated with the 3D vision systems such as dizziness, eye fatigue, nausea, headache, etc. [12].

The term 4K or ultra-high definition refers to a display having a horizontal resolution on the order of 4000 pixels and a vertical resolution on the order of 2000 pixels which is four times the resolution of high definition [13]. 4K technology is now coming to the operating theatre after becoming common in the television and cinema. The advantages of 4K technology include more detailed, color-correct images and greater depth perception [14]. There are assumptions that this would aid in avoiding conversion from laparoscopic to open procedures, reduce the operative time and help surgeons perform more complex laparoscopic procedures [14].

A power calculation with a power of 95% and an alpha level of 0.05 indicated that a minimum of 17 candidates were needed in each arm to show a significant difference. We aimed to compare the performance of

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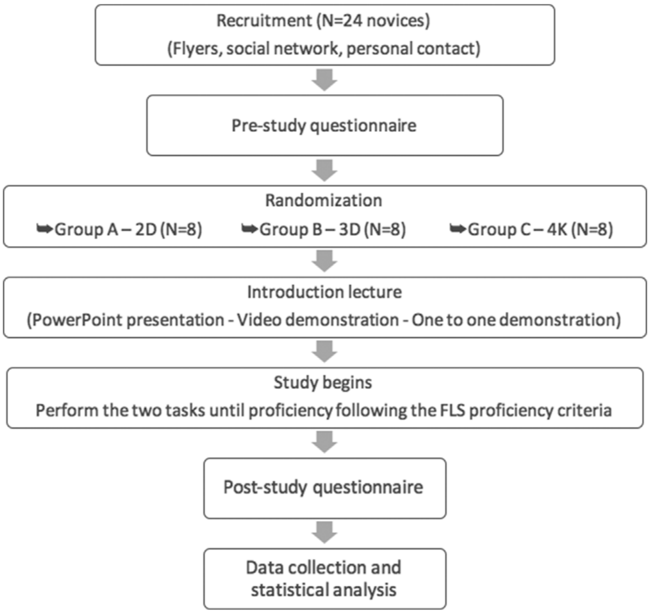

Fig. 1. The CONSORT diagram.

novices in laparoscopic peg transfer and intra-corporeal suturing tasks using 2D, 3D and 4K vision systems following a validated Fundamentals of Laparoscopic Surgery (FLS) curriculum with a preset proficiency criteria. In addition, we aimed to evaluate the adverse effects that may occur with the three vision systems using a validated simulator sickness questionnaire.

2. Materials and methods

The study was planned in accordance with the CONSORT statement (Fig. 1). This was a prospective randomized study into which twenty-four participants who met the inclusion criteria were enrolled. The inclusion criteria were as follows: novice to laparoscopy, had no uncorrected sight problems, and are committed to complete the training curriculum. Participants with laparoscopic exposure beyond camera navigation were excluded. All candidates were medical student volunteers who fulfilled the inclusion criteria and gave their consent before the training started.

2.1. Tasks

The study tasks included peg transfer and intra-corporeal suturing. The selected tasks were taken from the validated Fundamentals of Laparoscopic Surgery (FLS) curriculum. Both tasks carries preset errors and proficiency criteria according to the validated FLS proficiency criteria (Fig. 2).

2.2. Materials and equipment

The LaproTrain box trainer was used; this box trainer contains a camera with a video display and a five skin-like access ports for the introduction of laparoscopic instruments. The monitor was 32 in. (LG 32LW450U; display type: LED, high definition, resolution 1920 × 1,080, motion clarity index: 400 Hz). In the 3D group, the candidate wore passive polarized 3D glasses (weight:16 g), and the camera was a Sony camcorder model 3D in Double Full HD, 1920 × 1080 Full HD 60p/24p recording. In the 4K group, the monitor was 40 in. Panasonic Viera (TX-40 C × 400 B, LCD, 4K, Ultra- HD, resolution 3840 × 2160), and the camera was a Panasonic camcorder HC-WX970 (4K, Ultra-HD, Camcorder with Twin Video Camera, resolution 3840 × 2160).

2.3. Recruitment and training sessions

The candidates were blindly randomized into three groups (2D, 3D and 4K groups) using a computer-generated randomization. The candidates completed a pre-study questionnaire exploring their demographic information and were provided with written instructions. Then, an introductory lecture was given by an instructor and was followed by a short FLS video demonstrating the tasks. Candidates were given brief instructions about the box trainer and the instruments used for each task. Candidates from the 3D group went through an adaptation exercise that involved looking at a static 3D image on the monitor

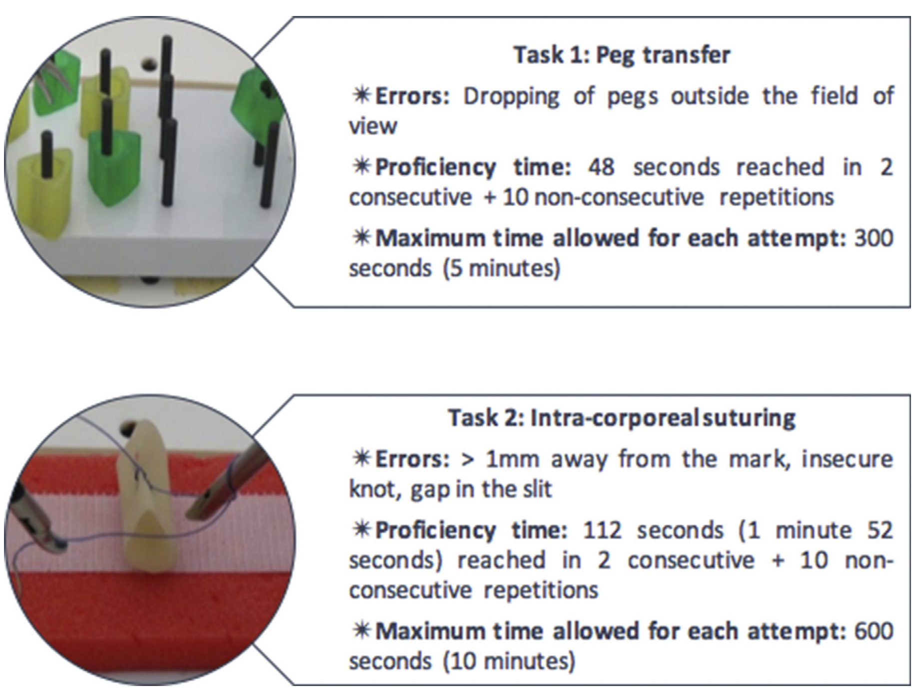

Fig. 2. Tasks errors and proficiency criteria.

No______________ Date____________________

SIMULATOR SICKNESS QUESTIONNAIRE

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Last version : March 2013

***Original version : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology*, *3*(3), 203-220.

Fig. 3. Simulator sickness questionnaire.

Table 1
Candidates demographics.

Groups	2D group (n = 8)	3D group (n = 8)	4K group (n = 8)
Gender (male/female)	1/7	3/5	5/3
Mean age (range) (years)	23.5 (19–25)	23 (20–26)	23.5 (19–29)
Dexterity (right/left)	7/1	8/0	6/2
Interest in surgical career (yes/no/not sure)	4/0/4	7/0/1	5/0/3

alternating 10 s and 10 s away for a minimum of 2 min; before the training began. Each task was demonstrated once by the same instructor and followed by a single hands-on exercise by the participants, which was intended to familiarize them with the instruments. Following the FLS guidelines and the FLS technical skills proficiency-based training curriculum [15,16,17], candidates initiated training with task 1 peg transfer, then progressed to task 2 intra-corporeal suturing. Tasks were performed in order, and the maximum number of repetitions allowed per task was 80 attempts; however, if the participant reached 80 attempts for one task but failed to achieve proficiency, he or she would move to the next task. The candidates were allowed the maximum time for each attempt which differs from one task to another according to FLS proficiency criteria (Fig. 2). If the candidate exceeded the time allocated for the attempt, he or she was stopped to start over again. Multiple sessions were arranged for training a maximum of 2 h/day. A validated simulator sickness questionnaire (Fig. 3) [18] was used to evaluate any symptoms such as headache, nausea, dizziness or blurring vision. Upon successful completion of the training curriculum all participants completed a post-study questionnaire to determine their views about depth perception, eye-hand co-ordination on a scale of one to five, where one is extremely easy and five is extremely difficult.

2.4. Statistical analysis

Three parameters were considered for analysis (completion time, number of errors, number of repetitions to reach proficiency), the total completion time was used for sample size calculation. A power calculation with a power of 95% and an alpha level of 0.05 was done for our study indicated that a minimum of 17 candidates were required in each arm to show a significant difference. The results were initially collated in Excel spreadsheets (Microsoft Corporation, Redmond, WA, USA) and transferred to Prism 6 (GraphPad Software, Inc.). The data was expressed as mean (standard deviation) and compared using One-way ANOVA test. Statistical significance was considered at the 5% level ($P < 0.05$).

3. Results

All participants completed the study successfully. There were a total of 9 males and 15 females, with nearly equal mean ages. Most of the candidates were right-handed, while one candidate of the 2D group, and two candidates of the 4K group were left-handed. The vast majority of the candidates in both groups were interested in pursuing a surgical career (Table 1). In the analysis of the performance times, the 3D group took overall less time to complete the peg transfer task compared to the 4K group (P value = 0.9301); but in the intra-corporeal suturing task the 4K group took overall less time to complete the task compared to the 3D group (P value = 0.9176). However, the 2D group took significantly longer time to complete the two tasks compared to the 3D and the 4K groups (P value < 0.0001). Analysis of the number of repetitions to reach proficiency showed that there were no differences between the three groups for the peg transfer task, as none of the participants in the three groups managed to reach proficiency in the 80 attempts allowed for this task; however the 2D group performed significantly greater number of repetitions for the intra-corporeal suturing task than the 4K and the 3D group respectively (P value < 0.0001). The error scores were significantly greater in the 2D group in the two tasks compared to the 3D and the 4K groups (P value < 0.0003 and 0.0001, respectively). The error score was greater in the 3D group compared to the 4K group in the peg transfer task (P value 0.1156), but in the intra-corporeal suturing task the difference was statistically significant (P value = 0.0041).

The mean completion time for the 2D group was 558.3 min (SD: 94.6 min), which was greater than that of the 3D and the 4K groups of 316.7 min (SD: 87.9 min) and 310.4 min (SD: 35.6 min), respectively (P value < 0.0001). The mean number of repetitions to reach proficiency for the 2D group was 152 repetitions (SD: 7 repetitions), which was greater than that of the 4K and the 3D groups of 127 repetitions (SD: 6 repetitions) and 126 repetitions (SD: 12 repetitions), respectively (P value < 0.0001). The mean error score for the 2D group was 50 errors (SD: 14 errors), which was greater than that of the 3D and the 4K groups of 26 errors (SD: 14 errors) and 1 error (SD: 2 errors), respectively (P value < 0.0001) (Table 2).

A validated simulator sickness questionnaire (Fig. 3) [18] was used to evaluate the side effects. The questionnaire involved 16 possible types of side effects, with 4 levels of intensity (none to severe). The adverse effects were divided into 4 subgroups for analysis: physiological (burping, salivation increasing and sweating), mental (headache, dizziness with eyes open, dizziness with eyes closed, difficulty concentrating and fullness of the head), physical (general discomfort, fatigue, nausea, vertigo and stomach awareness) and visual (blurred vision, eye strain and difficulty focusing). The 3D vision system produced significant eye strain, blurred vision and difficulty in focusing than the 4k and the 2D systems (Table 4). There were no significant differences in the physiological, mental or physical side effects between the three visual modalities (Table 3).

Table 2
Difference between 2D, 3D and 4K groups in performance time, number of repetitions, and errors in FLS tasks.

FLS Tasks	Total time (minutes) Mean (± SD)			Total Repetitions Mean (± SD)			Total Errors Mean (± SD)		
	2D	3D	4K	2D	3D	4K	2D	3D	4K
Peg transfer	225.5 (± 35.9)*	155 (± 20.9)*	160 (± 24.3)*	80 (± 0)	80 (± 0)	80 (± 0)	7 (± 5)*	3 (± 2)*	0.1 (± 0.3)*
Intra-corporeal suturing	332.8 (± 65.9)*	161.6 (± 69.6)*	150.35 (± 24.8)*	72 (± 7)*	46 (± 12)*	47 (± 6)*	43 (± 15)*	23 (± 14)*	1 (± 2)*
Total group performance	558.3 (± 94.6)*	316.7 (± 87.9)*	310.4 (± 35.6)*	152 (± 7)*	126 (± 12)*	127 (± 6)*	50 (± 14)*	26 (± 14)*	1 (± 2)*

*Sig at 5% level, SD = Standard deviation.

Table 3
Comparison of reported side effects in 2D, 3D and 4K groups.

Side effects	2D group Average score (0–3)	3D group Average score (0–3)	4K group Average score (0–3)	P value
Physiological	0.1	0.4	0.04	0.1
Visual	0.1	1	0.1	0.0002
Mental	0.2	0.4	0.2	0.5
Physical	0.4	0.6	0.5	0.9

Table 4
Comparison of visual adverse effects in 2D, 3D and 4K groups.

Visual side effects	2D group Average score (0–3)	3D group Average score (0–3)	4K group Average score (0–3)	P value
Blurred vision	0	1	0	0.001
Eye strain	0	1	0	0.001
Difficulty focusing	0.3	0.9	0.3	0.04

In the post-study questionnaire, on a scale of one to five (1 = extremely easy and 5 = extremely difficult) majority of the participants felt ability to perceive depth and eye hand co-ordination were easier in the 3D group with a mean score of 2.3 and 2.5 respectively, compared to the 4K group with a mean score of 3.5 and 3.2 respectively, and the 2D group with a mean score of 3.6 and 3.5 respectively.

4. Discussion

Although recent studies [2,6,7,19] have shown that 3D laparoscopy improves efficiency and accuracy of the performance of laparoscopic tasks compared to the conventional 2D vision system, the 3D laparoscopy is not widely used due to its high cost, sporadic availability, associated visual adverse effects (eye strain, blurred vision and difficulty in focusing) and the fact that the operator needed to wear an extra eyewear.

Few studies only did the full number of repetitions according to the FLS curriculum, Alaraimi et al. [3] compared between 2D and 3D vision systems using FLS tasks and found that the median number of repetitions to reach proficiency in 2D and 3D vision systems in peg transfer task were 80, while in intra-corporeal suturing the median number of repetitions in 2D and 3D were 22 and 12 respectively. In our study, the mean number of repetitions in 2D, 3D and 4k in peg transfer task were 80 as well. However, in the intra-corporeal suturing task the mean number of repetitions in 2D, 3D and 4k were 72, 46 and 47 respectively. This might be explained by the fact that, in the other study the candidates performed more tasks such as endoloop and extracorporeal suturing before practicing intra-corporeal suturing.

One of the limitations of this study is the sample size, we did a power of calculation and we found that we need a minimum of 17 participants in each arm in order to get significant results specially when comparing the 3D group and the 4K group regarding the error score in the basic task (Peg transfer), the overall time to complete both tasks and the number of repetitions to reach proficiency in both the basic and advanced tasks. However, comparing the error score in the advanced task with 8 participants in each arm was statistically significant with a P value = 0.0041. Another limitation was the female-male ration especially in the 2D group. However, in the 3D and the 4K groups the ratios were nearly equal.

However, the 3D group should be expected to demonstrate better results vs the 4K group regarding the task of intracorporeal suturing because of the role of the third dimension, this study showed that the 4K group had significantly less errors than the 3D group. This could be explained by how participants reported the ease with which they could perform the task using the 4K system and the effect of the image quality in improving efficiency through avoidance of unnecessary steps. Also the reported side effects of the 3D system such as eye fatigue, blurred vision and difficulty in focusing may have played an important role towards contributing more errors specially in advanced tasks.

We believe that the 4K system despite being a 2D image system with ultra-high definition power but still the effect of the image quality is very important in reduction of mistakes in structure identification which will in turn reduce errors.

We have also reported that perceiving depth in the 3D group was easier than the 4K and the 2D groups respectively, which explains one of the significant features of the 3D systems known as the ‘’depth’’ dimension in the laparoscopy.

According to our results this paradox ‘’ no depth but better accuracy and less errors’’ could be explained with the ultra-high definition power and the image quality of the 4K systems which improves depth perception compared with the 2D systems and also avoids the reported side effects of the 3D systems. This is certainly a research question of interest whether improving image quality such as 4K and 8K will end the depth legend.

There are no available studies in the literature comparing between the 4K vision system and any other vision systems. This study showed some interesting outcomes comparing the 4K vision system with the 3D and the 2D vision systems in laparoscopic simulators. The 3D and the 4K groups required less time and had lower error scores than the 2D group in the basic and the advanced tasks. Also the number of repetitions to reach proficiency were less in the 4K and the 3D groups compared to the 2D group in the advanced task. The 4K group had lower error score in the advanced task than the 3D group. With the differences being statistically significant.

5. Conclusions

This study has demonstrated that the 4K and 3D vision systems results in better performance and quicker acquisition of laparoscopic skills when compared to the conventional 2D vision system for novices. Moreover, the use of the 4K vision system improves accuracy in advanced tasks and that was shown in significant reduction in number of errors compared to the 3D and 2D vision systems.

A larger sample size is required to achieve more significant results especially between the 4K and 3D vision systems. We recommend comparing the performance of expert surgeons on the three vision systems, and to compare the three systems in a clinical setting. We believe also that we need more studies comparing between the full HD laparoscopic stack and the 4K laparoscopic stack.

Ethical approval

No ethical approval was need.

Sources of funding

None.

Author contribution

Amjad Belramman: Study design, data collections, data analysis.
Riadh Salem: Study design, data collections, data analysis.
Mr Bijendra Patel: Main supervisor, study design, data collections, data analysis, writing.

Conflicts of interest

None.

Research registration number

It is not a human study.

Guarantor

All authors.

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