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3D Versus 4K Display System – Influence of "State-of-the-art"-Display Technique on Surgical Performance (IDOSP-study) in Minimally Invasive Surgery

A Randomized Cross-over Trial

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Objective: To evaluate if "state-of-the-art" 3D- versus 4K-display techniques could influence surgical performance.

Background: High quality minimally invasive surgery is challenging. Therefore excellent vision is crucial. 3D display technique (3D) and 2D-4K technique (4K) are designed to facilitate surgical performance, either due to spatial resolution (3D) or due to very high resolution (4K).

Methods: In randomized cross-over trial the surgical performance of medical students (MS), non-board certified surgeons (NBC), and board certified surgeons (BC) was compared using 3D versus 4K display technique at a minimally invasive training Parkour.

Results: One hundred twenty-eight participants were included (February 2018 through October 2019, 49 MS, 39 NBC, 40 BC). The overall Parkour time (s) 3D versus 4K was 712.5 s ± 17.5 s versus 999.5 s ± 25.1 s ($P < 0.001$) for all levels of experience. It was (3D vs 4K) for MS (30 tasks) 555.4 s ± 28.9 s versus 858.7 s ± 41.6 s, ($P < 0.0001$), for NBC (42 tasks) 935.9 s ± 31.5 s versus 1274.1 s ± 45.1 s (P =< 0.001) and for BC (42 task) 646.3 s ± 30.9 s versus 865.7 s ± 43.7 s ($P < 0.001$). The overall number of mistakes was (3D vs 4K) 10.0 ± 0.5 versus 13.3 ± 0.7 ($P < 0.001$), for MS 8.9 ± 0.9 versus 13.1 ± 1.1 ($P < 0.001$), for NBC 12.45 ± 1.0 versus 16.7 ± 1.2 ($P < 0.001$) and for BC 8.8 ± 1.0 versus 10.0 ± 1.2 ($P = 0.18$). MS, BC, and NBC showed shorter performance time in 100% of the task with 3D (significantly in 6/7 tasks). For number of mistakes the effect was less pronounced for more experienced surgeons. The National Aeronautics and Space Administration-task load index was lower with 3D.

Conclusion: 3D laparoscopic display technique optimizes surgical performance compared to the 4K technique. Surgeons benefit from the improved visualization regardless of their individual surgical expertise.

Keywords: 3D, 4K, laparoscopic surgery, minimally invasive surgery, surgical performance, surgical training

(*Ann Surg* 2020;272:709–714)

Minimally invasive surgery (MIS) has become the preferred technique for many different surgical procedures. Especially the number of complex laparoscopic operations has increased during the last decade.[1] Patients benefit from MIS.[2] For surgeons these procedures are demanding with a relevant learning curve and longer operation times and challenging intraoperative complication management.[3,4] Therefore optimal visualization of the operative field is crucial. In MIS the 3-dimensional (3D) real world is reduced to virtual 2-dimensions (2D) with the loss of spatial orientation. For novices this makes surgery more difficult, but surgical experience seems to equalize this.[5] 3D imaging technique combined with full high-definition displays (1920 × 1080 pixel) has reintroduced stereoscopic vision to MIS. Driven by consumer electronics 2D-4K ultra-high definition display technique (4098 × 2160 pixels) reached surgery. Creating high resolution images with a magnification up to 30 times on 55″ (140 cm) screen, the 4K technique has the potential to optimize the surgical performance. It is promoted as an alternative to the 3D technique. Equipment for both is expensive. The evidence on that topic is scarce and controversy. It is not clear who and which situations are influenced by the 3D or 2D-4K display technique.[6] In this randomized cross over trial medical students (MS), non-board certified (NBC) and board-certified surgeons (BC) have performed repeatedly a standardized minimally-invasive training Parkour with a 3D and 2D-4K display system. Aim of the IDOSP-trial was to evaluate, if these state-of-the-art display techniques could optimize the surgical performance.

METHODS

Trail Oversight/Ethics

This investigator–initiated trial was designed as randomized cross-over, single-blinded trial by the lead investigators and a statistician. Approval was obtained from the Ethics Committee of the University Hospital of Cologne (No. 17-388). Written informed consent was obtained from all participants before randomization by the independent data trustee. Data were collected by the investigators. Statistical analysis was performed at the Institute of Medical Statistics and Computational Biology. The authors analyzed the data, and wrote

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No external funding was received for this study.
There was no funding by the National Institutes of Health (NIH); Wellcome Trust; Howard Hughes Medical Institute (HHMI); and other(s).
The authors declare no conflict of interest.
Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.annalsofsurgery.com).

ISSN: 0003-4932/20/27205-0709
DOI: 10.1097/SLA.0000000000004328

the manuscript, vouched for the accuracy of the analyses and the fidelity of the trial to the protocol. There was no external funding. The study was registered at clinicaltrial.gov (NCT03445429). The study protocol was published upfront in Trials.[7]

Participants

All participants were volunteers. The MS came from the University of Cologne. The NBC and BC were members of the Department of General, Visceral, Cancer and Transplant Surgery, surgeons from the Department of Gynecology and Urology of the University Hospital of Cologne and surgeons of 9 secondary hospitals of the Cologne area.

Excluded from the trial were MS with any experience in laparoscopy, subjects with general experience in the minimally invasive training Parkour, non-correctable vision disorders, known impaired stereoscopic vision or manual skill disorders.

Trial Design

This trial compared the surgical performance at a minimally-invasive training Parkour. The participants (MS, NBC, BC) were randomized to start the Parkour with the 3D display system followed by a second turn with the 4K display system or vice versa. Each run included 7 tasks (5 for MS) of different complexity and was repeated 3 times in a row. In sum each participant performed 42 (30 for MS) tasks, 21 (15 for MS) with the 3D and with the 4K system. The task were called "rope pass," "paper cut," "pegboard transfer," "needle threading," "needle recapping," "circle cutting," and "knot tying," in part inspired by the fundamentals of laparoscopic surgery simulator.[8] MS did not perform the tasks "circle cutting" and "knot tying." A detailed description of the minimally-invasive training Parkour could be found in the published study protocol.[7] The participants' task load of each run was evaluated by the National Aeronautics and Space Administration Task Load Index (NASA-TLX).[9] After the Parkour an ophthalmological evaluation of stereoscopic vision followed.[10] The performance of the Parkour was video documented. The videos were evaluated by 2 blinded independent investigators according to a protocol. The passive polarizing 3D laparoscopic system "Einstein Vision 2.0" (10 mm 30° camera, 3D full high-definition 32″ monitor, Aesculap AG, Tuttlingen, Germany) and the 2D-4K System "Visera 4K Ultra High Definition" (10 mm 30° camera, 55″ monitor, Olympus Medical system Olympus Europa SE & Co. KG, Hamburg, Germany) were used. It was hypothesized, that one of both display techniques facilitate MIS. From preliminary experiments of the study group and published data a standardized effect of 0.5 in favor of the 3D system was expected. A sample size of 34 per stratum is required to detect this standardized effect of 0.5 with a power of 80% at 2-sided type I error 5%.[7]

Primary Outcome

The primary outcome parameter surgical performance was defined by the items "time in seconds" and "number of mistakes" for each task. In addition an overall Parkour performance time and number of mistakes were evaluated. A mistake was defined as deviation from perfect performance. The detailed definition for the mistakes was described in the study protocol.[7]

Secondary Outcome

The secondary outcome parameter was the NASA-TLX-score (http://links.lww.com/SLA/C426).

Statistical Analysis

Quantitative variables are summarized by n, mean $\pm$ standard deviation, qualitative variables by count and percentage. Outcome measures (average of 2 observers' measurements) were evaluated by linear mixed models for repeated measures with main effects experience, sequence, method, repetition, and interactions (type III sum of squares, restricted maximum likelihood, heterogeneous compound symmetry covariance matrix). Estimated marginal means and contrasts are derived. For these contrasts Wald-type test statistics and corresponding P-values were calculated. Two-sided P-values $< .05$ are interpreted to indicate statistical significance. Calculations were done with SPSS Statistics 26 (IBM Corp., Armonk, NY).

RESULTS

One hundred thirty-three subjects were randomized between February 2018 and March 2019. Last data of the ophthalmologic examination were transferred in October 2019. One hundred twenty-eight subjects could be included to the final data analysis. Supplementary Figure 1, http://links.lww.com/SLA/C530 shows information on randomization, intervention, and analysis.

Characterization of Study Sample

The age of the MS was 25.0 ± 4.0 years, of the NBC 30.0 ± 4.4 years, and of the BC 43.0 ± 8.3 years. In the MS stratum 45% were female and 55% male, in the NBC surgeons stratum 72% were female and 28% male and in the BC surgeons stratum 18% were female and 82% male. Students were at medical school for 6.9 ± 2.70 academic terms. Work experience for NBC was 4.2 ± 4.0 years and for BC 16.4 ± 8.6 years (board certification for 10.1 ± 8.5 years). 36.0% of NBC and 70.0% of BC had experience with a laparoscopic training Parkour. 26.6% use a 3D display and 13.9% a 4K display system in their surgical routine. 90.6% were right handed and 51.6% had a correction of visual acuity. 95% of the participants showed normal stereoscopic vision (Titmus-test).

Primary Outcome Parameters

The overall Parkour time in seconds comparing 3D versus 4K was 712.5 s $\pm$ 17.5 s versus 999.5 s $\pm$ 25.1 s ($P < 0.001$) combined for all levels of experience. It was (3D vs 4K) for MS (30 tasks) 555.4 s $\pm$ 28.9 s versus 858.7 s $\pm$ 41.6 s, ($P < 0.001$), for NBC surgeons (42 tasks) 935.9 s $\pm$ 31.5 s versus 1274.1 s $\pm$ 45.1 s ($P =< 0.001$) and for BC surgeons (42 task) 646.3 s $\pm$ 30.9 s versus 865.7 s $\pm$ 43.7 s ($P < 0.001$). The overall number of mistakes for the complete laparoscopic Parkour combined for all level of experience comparing 3D versus 4K was 10.0 ± 0.5 versus 13.3 ± 0.7 ($P < 0.001$), for MS it was 8.9 ± 0.9 versus 13.1 ± 1.1 ($P < 0.001$), for NBC 12.45 ± 1.0 versus 16.7 ± 1.2 ($P < 0.001$) and for BC 8.8 ± 1.0 versus 10.0 ± 1.2 ($P = 0.18$) (Fig. 1).

The overall Parkour time for the sequence 3D before 4K versus 3D after 4K was 790.4 s $\pm$ 25.2 s versus 634.6 s $\pm$ 24.4 s ($P > 0.001$) and for the sequence 4K before 3D versus 4K after 3D it was 1098.8 s $\pm$ 36.5 s versus 900.1 s $\pm$ 34.5 s ($P < 0.001$). The overall number of mistakes for the sequences 3D before 4K versus 3D after 4K was 10.1 ± 0.8 versus 10.0 ± 0.8 ($P = 0.96$) and for the sequence 4K before 3D versus 4K after 3D it was 14.7 ± 1.0 versus 11.8 ± 0.9 ($P = 0.04$).

Table 1 shows the performance for each task. MS, BC, and NBC showed shorter performance time in 100% of the task using the 3D display system. The results were statistically significant for all tasks but "needle recapping."

Table 2 shows the number of mistakes for each task. In 71% the number of mistakes was lower with the 3D system versus 4K. The results were significant for MS in all tasks but "paper cut," for NBC in 4/7 tasks ("rope pass," "needle threading," "needle recapping," "knot tying") and for BC in 3/7 tasks ("pegboard transfer," "needle threading," "needle recapping"). In "paper cut" and "circle cutting" lower number of mistakes were achieved with the 4K system. "Paper cut" was the only task were MS and board certified surgeons made significantly less mistakes with 4K.

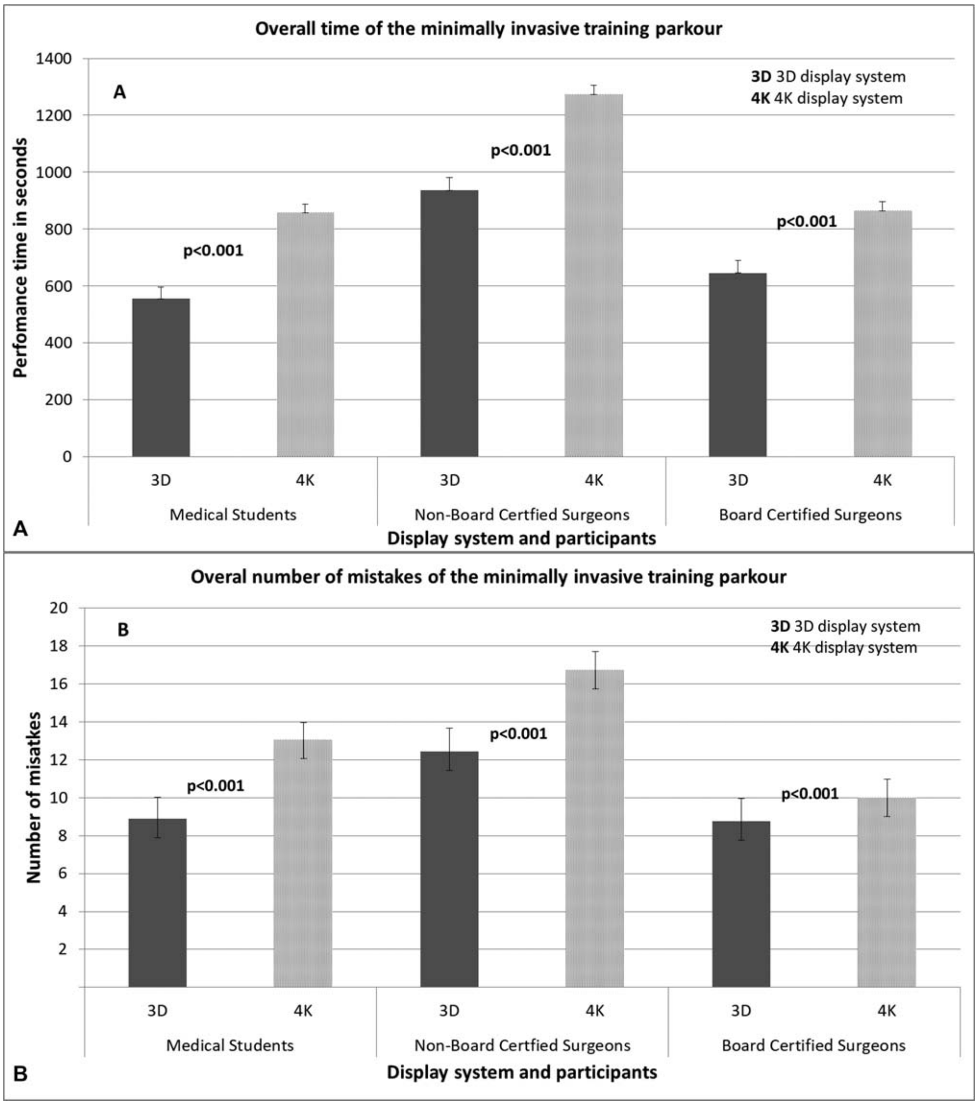

FIGURE 1. Overall parkour time and overall number of mistakes comparing 3D versus 4K display system at the minimally invasive training parkour –medical students, non-board certified surgeons, and board certified surgeons. Figure 1 shows the overall parkour time (A) and the overall number of mistakes (B) comparing 3D versus 4K display system according to the level of surgical experience. The overall performance time was significantly shorter and the overall number of mistakes was significantly lower using the 3D display system compared to the 4K display system for all levels of experience (medical students, non-board certified surgeons, and board certified surgeons).

Figure 2 show the course of the performance time and the course of mistakes for every single participant (MS, BC, and NBC) represented by 1 colored line for the task ''rope pass.'' The performance time continuously dropped to its minimum at the end, for participants that started with the 4K system and finished the Parkour with the 3D systems. The subjects that started with the 3D system reached the shortest time with the 3D system after 3 repetitions, followed by an increase of the performance time with the 4K system, not reaching the 3D-minimum again. For the course of mistakes a comparable trend could be seen.

Secondary Outcome Parameter

The task load felt by the participants and evaluated by the NASA-TLX questionnaire was significantly lower using the 3D versus 4K system (3D vs 4K: overall 48.6 ± 1.5 vs 61.9 ± 1.3 $P < 0.001$, for MS 50.3 ± 2.3 vs 66.6 ± 2.1, $P < 0.001$, for NBC 57.2 ± 2.6 vs 66.4 ± 2.3, $P < 0.001$ and for BC 38.32 ± 2.6 vs 52.7 ± 2.3, $P < 0.001$).

DISCUSSION

3D display technique returned spatial orientation to minimal invasive surgery. There seem to be a benefit of this technique compared to 2D-HD systems, but this is still discussed controversy.[6,11] 2D-4K ultra-high definition display could create a high resolution image of the operative field, which may also improve surgical performance. Data comparing 3D versus 4K technique is rare, especially data that compares different levels of experienced

TABLE 1. Surgical Performance Comparing 3D Versus 4K Display System – Mean Performance Time in Seconds of Each Task of the Minimally Invasive Training Parkour – Medical Students, Non-board Certified Surgeons, and Board Certified Surgeons

	3D Rope Pass	4K Rope Pass	P	3D Paper Cut	4k Paper Cut	P	3D Pegboard Transfer	4K Pegboard Transfer	P	3D Needle Threading	4K Needle Threading	P
All (n = 128)	56.6 ± 1.3	82.7 ± 2.2	<0.001	106.0 ± 4.6	136.6 ± 6.3	<0.001	102.0 ± 1.8	138.0 ± 2.9	<0.001	95.9 ± 6.2	201.3 ± 11.7	<0.001
Medical students (n = 49)	75.5 ± 2.1	119.1 ± 3.5	<0.001	131.1 ± 7.6	175.5 ± 10.5	<0.001	116.9 ± 2.9	170.4 ± 4.6	<0.001	129.1 ± 10.0	271.7 ± 19.1	<0.001
NBC-surgeons (N = 39)	50.6 ± 2.4	70.3 ± 3.9	<0.001	108.1 ± 8.2	130.3 ± 11.2	0.008	105.0 ± 3.2	135.8 ± 5.1	<0.001	99.8 ± 11.1	212.3 ± 21.2	<0.001
BC-surgeons (n = 40)	43.6 ± 2.3	58.5 ± 3.8	<0.001	78.8 ± 8.2	104.0 ± 11.1	0.003	81.7 ± 3.2	107.7 ± 5.1	<0.001	58.8 ± 11.0	120.0 ± 20.6	0.001

	3D Needle Recapping	4K Needle Recapping		3D Circle Cutting	4K Circle Cutting		3D Knot Tying	4K Knot Tying	P
All (n = 128)	99.0 ± 14.8	134.0 ± 13.5	0.111	127.0 ± 4.7	144.9 ± 5.9	<0.001	280.4 ± 12.7	367.7 ± 15.2	<0.001
Medical students (n = 49)	141.9 ± 23.6	187.1 ± 21.8	0.297	ND	ND	ND	ND	ND	
NBC-surgeons (n = 39)	98.1 ± 26.8	131.4 ± 24.3	0.297	143.4 ± 6.6	156.3 ± 8.4	0.007	347.3 ± 18.2	456.3 ± 21.8	<0.001
BC-surgeons (n = 40)	57.2 ± 26.2	83.4 ± 24.0	0.401	110.5 ± 6.6	133.5 ± 8.4	<0.001	213.4 ± 17.7	279.1 ± 21.3	<0.001

3D indicates 3-dimensional display system; 4K, 2D-4K ultra-high definition display system; BC, board certified; NBC, non-board certified; ND, not done according to study protocol; *P*, *P*-value.

participants. Aim of this study was to evaluate, if state-of-the-art 3D versus 2D-4K display technique could influence and optimize the surgical performance in terms of different level of laparoscopic experience in a standardized experimental setting.

The main finding of this trial was that 3D display technique reduces performance time in a minimally invasive training Parkour compared to 4K display technique. It was significantly shorter for MS, surgeons in their residency and highly experienced BC surgeons. The effect on performance time was strong reaching up to a 53% decrease. The number of mistakes could also be reduced by the 3D system in the majority of the task, but this effect was more pronounced for less experienced participants and depends on the task. Only once (''paper cut'') the 4K system leads to significant lower number of mistakes. Although the use of the 3D system led to a reduction of mistakes, this effect was smaller compared to the achieved time benefit. Surgeons' task load, as measured by the

TABLE 2. Surgical Performance Comparing 3D Versus 4K Display System – Mean Number of Mistakes of Each Task of the Minimally Invasive Training Parkour - Medical Students, Non-board Certified Surgeons, and Board Certified Surgeons

	3D Rope Pass	4K Rope Pass	P	3D Paper Cut	4k Paper Cut	P	3D Pegboard Transfer	4K Pegboard Transfer	P	3D Needle Threading	4K Needle Threading	P
All (n = 128)	0.5 ± 0.1	1.5 ± 0.1	<0.001	2.2 ± 0.2	1.5 ± 0.2	<0.001	1.1 ± 0.1	1.5 ± 0.1	0.001	0.6 ± 0.1	1.2 ± 0.1	<0.001
Medical students (n = 49)	0.7 ± 0.1	2.5 ± 0.2	<0.001	2.2 ± 0.3	1.1 ± 0.3	<0.001	1.1 ± 0.1	1.6 ± 0.2	<0.001	0.6 ± 0.1	1.5 ± 0.2	<0.001
NBC-surgeons (n = 39)	0.4 ± 0.1	1.2 ± 0.2	<0.001	2.4 ± 0.4	2.4 ± 0.3	0.995	1.6 ± 0.1	1.7 ± 0.2	0.490	0.7 ± 0.1	1.4 ± 0.2	0.001
BC-surgeons (n = 40)	0.3 ± 0.1	0.6 ± 0.2	0.066	2.0 ± 0.4	1.0 ± 0.3	0.001	0.8 ± 0.1	1.1 ± 0.2	0.049	0.4 ± 0.1	0.8 ± 0.2	0.042

	3D Needle Recapping	4K Needle Recapping		3D Circle Cutting	4K Circle Cutting		3D Knot Tying	4K Knot Tying	P
All (n = 128)	3.9 ± 0.3	5.9 ± 0.4	<0.001	1.9 ± 0.5	2.3 ± 0.4	0.026	0.8 ± 0.1	1.2 ± 0.1	<0.001
Medical students (n = 49)	4.6 ± 0.4	7.0 ± 0.6	<0.001	ND	ND		ND	ND	
NBC-surgeons (n = 39)	4.2 ± 0.5	6.5 ± 0.7	0.001	1.9 ± 0.6	2.3 ± 0.6	0.158	1.0 ± 0.2	1.8 ± 0.2	0.000
BC-surgeons (n = 40)	2.7 ± 0.5	4.1 ± 0.7	0.044	1.9 ± 0.6	2.4 ± 0.6	0.082	0.7 ± 0.1	0.6 ± 0.2	0.925

3D indicates 3-dimensional display system; 4K, 2D-4K ultra-high definition display system; BC, board certified; NBC, non-board certified; ND, not done according to study protocol; *P*, *P*-value.

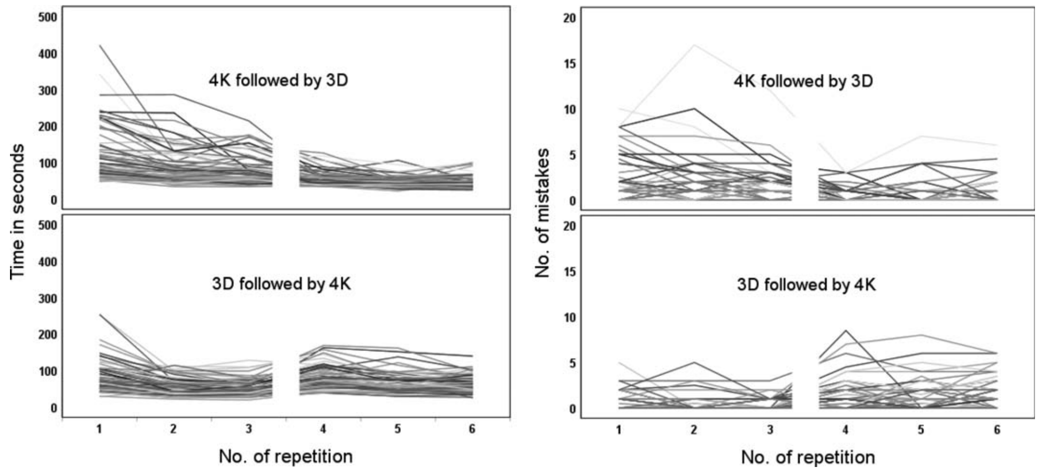

FIGURE 2. Course of ''performance time'' and ''number of mistakes'' in the minimally invasive training parkour for every participant - task ''rope pass''. Figure 2 show the course of performance time (A, B) and the course of mistakes (C, D) for every single participant represented by a colored line (medical students, non-board certified surgeons, and board certified surgeons) as the minimally invasive training parkour was run through per protocol (3 repetitions with one display system followed by 3 repetitions with the second display system). The white bar between repetition 3 and 4 marks the switch of the display systems (from 3D to 4K or vice-versa). The performance time continuously dropped to its minimum at the end, for the group that started with 4K system and finished the parkour with the 3D systems. Participants that started with the 3D system reached the shortest time with the 3D system in general after 3 repetitions followed by an increase of the performance time with 4K system, not reaching the 3D-minimum again. For the number of mistakes a comparable trend could be seen with a higher grade of deviation. **3D** 3D display system, **4K** 4K display system, **No.** number.

NASA-TLX, was significantly lower using the 3D system, especially for the experienced surgeons.

Spatial orientation in the operative field created by the 3D system seems to be relevant. This hypothesis is supported by the shorter performance time and lower number of mistakes achieved with the 3D system. The fact that even experienced surgeons show better results with the 3D system, underlined the effect, especially in task like ''rope pass'' and ''needle threating,'' where spatial orientation with fast and precise instrument movement is evaluated. The 2D-4K system despite the ultra-high resolution and magnification could not equalize the 3D effect there. 3D technique seems to create conditions to speed-up movement. Also the fact that less experienced surgeons have a high benefit from the 3D system could be relevant, wherever interaction between 2 surgeons of different level of experience is needed. This may explain the time benefit of 3D-systems in complex procedures but not in basic ones. This might also be reflected by the lower task load felt by the younger surgeons using 3D in contrast to 4K.

The data of this trial show that there is a training effect in the course of the repetitions during the laparoscopic Parkour. If a specific laparoscopic training with 3D before 4K or vice versa is helpful and could influence the surgical performance should be subject to future studies.

Multiple parameters are described that could lead to a conflict of evidence in the published literature about the 3D display technique: studies of different time periods, unconsidered experience level of the participants, inadequate tasks or surgical procedures, equipment not at eye level, inadequate study design, unconsidered learning curves, subjective qualitative reports and chosen outcome variables.[12,13] The IDOSP-Trial tried to consider these factors to generate high level evidence.

In a study published in the Lancet in 1998 by Hanna, Shimi, and Cuschieri, including 60 laparoscopic cholecystectomies performed by 4 specialist registrars, there was no difference in performance time or error rate comparing 3D versus 2D technique.[14] This data could be influenced by the premature, bulky 3D-technique of this era. A Cochrane analysis from 2011 came to the conclusion, that due to the limited number of trials (2 trials, 60 patients) no definitive conclusion could be drawn.[15] In a review 5 years later including 3 clinical and 28 experimental studies, 3D laparoscopy improved speed and reduced number of errors in contrast to 2D laparoscopy.[11] A clinical relevant benefit of the 3D technique seems to apply to more complex laparoscopic procedures like pancreas, liver, upper GI surgery or living kidney donation.[16–19]

Experienced surgeons benefit from 3D versus 2D technique as shown by Smith et al: 20 experienced surgeons showed a 62% and 35% reduction of errors and time in a laparoscopic skill parkour.[20] Our data support these, although we saw a stronger effect on time reduction than on mistake rate in experienced surgeons.

Ultra-high definition 4K systems should challenge the existing 3D systems. This was the main aspect to be evaluated in this trial. In a non-randomized study comparing 40 novice surgeons without prior surgical skills using the 3D versus 4K systems in laparoscopic training Parkour, a reduction of errors but not for time could be seen.[21] Our study showed a benefit in the novice groups in both performance parameters. A reason for that could be that in the IDOSP-Trial 5–7 tasks with more complexity and variation and a relevant number of repetitions were performed without the option of prior practicing. Especially rapid precise movement in combination with spatial orientation was evaluated in IDOSP (task ''rope pass'' and ''needle threading''). In a clinical trial in 109 laparoscopic cholecystectomies, performed by 3 consultant surgeons, neither operative time (23 minutes vs 21 minutes) nor the number of mistakes (60 vs 58) were influenced by the 3D or 4K technique.[22] This operative setting might not be challenging enough due to static preparation in Calot triangle combined with experienced surgeons to discriminate an effect between one of the high-end display systems. In certain situations 4K technique might be beneficial: Harada et al compared minimally invasive suturing tasks performed by expert laparoscopic surgeons and saw an improved surgical performance with the 3D compared to 4K, but in narrow spaces with low grades of instrument movement 4K and 3D were comparable.[23] This was also reflected by the IDOSP- trial, where 4K only once outperformed the 3D system: in ''paper cut'' a static precise cut of exact 5 mm length cm on a 2 mm wide line should be performed. Here ultra-high resolution and zoom could be of value.

Shorter procedure time could reduce complications in MIS.[24] The 3D compared to 4K system has the potential to reduce procedure time even for experienced surgeons up to 25% (120 minutes of an 8 hour running operation theater). If additional surgical procedures would be performed in this available operation theater time (120 minutes) German Diagnosis Related Groups related proceeds from 5211€ (staging laparoscopy in cancer patients) to 12558€ (laparoscopic distal pancreatectomy) could be generated.

A potential bias of this trial could be the previous routine use of the 3D or 4K system by some surgeons. According to multivariable statistical analysis, it did not significantly affect the outcome parameter ''surgical performance'' in this trial. Another bias could be the use of display systems from 2 manufacturers. The huge 55″ (140 cm) screen of the 4K system might be a bias and advantage over the 3D system, but this seemed to be of minor relevance regarding the study results. The randomized cross over design, the high number of tasks and repetitions and the inclusion of participant of different levels of experience strengthen our experimental results. It might be very difficult to design future clinical trials in complex minimally invasive surgical procedure that generate robust data. These procedures show a high intraoperative variability between centers and surgeons and only a limited number of surgeons perform these highly specialized operations. Thus it might be difficult to design a clinical trial that includes a similar number of surgeons in a comparable clinical setting. In conclusion this trial shows that the 3D display technique could optimize surgical performance compared to the 4K technique. In particular this trial could show that besides novices also surgeons in-training and experts have a relevant benefit from the 3D display technique.

ACKNOWLEDGMENTS

The authors would like to thank the Cologne Surgical Society and its members represented by Tobias Beckurts, Ernst Eypasch, Christian Kriegelstein, Anton Kroesen, Marcus Overhaus, and Andreas Rink, and the department of urologic surgery of the University Hospital of Cologne represented by David Pfister, Florian Hartmann, and Axel Heidenreich for supporting this trial. Furthermore we like to thank Christoph Denz and David Jones, who organized operation theater capacity for the study during the daily clinical routine and Kerstin Kaiser, who provided the economic data for cost analysis.

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