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# New dimensions in surgical training: immersive virtual reality laparoscopic simulation exhilarates surgical staff

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**Abstract**
*Introduction* Virtual reality (VR) and head mount displays (HMDs) have been advanced for multimedia and information technologies but have scarcely been used in surgical training. Motion sickness and individual psychological changes have been associated with VR. The goal was to observe first experiences and performance scores using a new combined highly immersive virtual reality (IVR) laparoscopy setup.
*Methods* During the study, 10 members of the surgical department performed three tasks (fine dissection, peg transfer, and cholecystectomy) on a VR simulator. We then combined a VR HMD with the VR laparoscopic simulator and displayed the simulation on a 360° video of a laparoscopic operation to create an IVR laparoscopic simulation. The tasks were then repeated. Validated questionnaires on immersion and motion sickness were used for the study.
*Results* Participants' times for fine dissection were significantly longer during the IVR session (regular: 86.51 s [62.57 s; 119.62 s] vs. IVR: 112.35 s [82.08 s; 179.40 s]; $p = 0.022$). The cholecystectomy task had higher error rates during IVR. Motion sickness did not occur at any time for any participant. Participants experienced a high level of exhilaration, rarely thought about others in the room, and had a high impression of presence in the generated IVR world.
*Conclusion* This is the first clinical and technical feasibility study using the full IVR laparoscopy setup combined with the latest laparoscopic simulator in a 360° surrounding. Participants were exhilarated by the high level of immersion. The setup enables a completely new generation of surgical training.

**Keywords** Immersive virtual reality · Virtual surgery · Laparoscopy · Simulation · Abdominal surgery · Training

Virtual reality (VR) laparoscopic simulation has been used for training of the basic psychomotor skills used in laparoscopic surgery [1]. According to the visions of Satava in 1993 [2], the VR tasks, graphic design, and tissue behavior have been improved since the development of VR laparoscopic simulators. According to van Dongen et al. [3], the voluntary use of VR simulators is low, and these training methods have to be integrated into a mandatory curriculum. Thus, currently available VR laparoscopic simulators are not very appealing. One reason for this may be the degree of immersion. Current analyses are limited to training in an empty operating room (OR) sometimes in combination with team training sessions with an anesthesiologist or scrub nurse. Nonetheless, training usually takes place outside of the OR [4–6]. Immersive virtual reality (IVR) with head-mounted displays (HMDs) has been used in information and multimedia technologies. First clinical applications have been described for pain management or psychological interventions [7, 8]. However, there have also been reports of the negative aspects of VR such as motion sickness, loss of reality, and psychopathological effects [9, 10]. The next step in surgical simulation is the integration of the newly available VR HMDs in combination with validated VR laparoscopic simulators [11].

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The goal of the current project was to develop a new combined highly IVR laparoscopy setup and to analyze first experiences regarding the degree of immersion, motion sickness, and performance measurements.

## Methods

### Study design

The study population consisted of 10 members of the surgical department (three females) with varying laparoscopic experience levels (two attending surgeons, two surgical fellows, two PGY-5, two PGY-2, and two medical students). We categorized the participants into "experienced" (attending, fellow, PGY-5; $n=6$) and "inexperienced" (PGY-2 and medical students; $n=4$) according to the number of performed laparoscopic surgeries. All participants were right handed. Overall, five participants never played video games, six had prior short exposure to a VR HMD, and no participant owned a VR HMD. All participants had prior experience with the laparoscopic simulator used ($n=10$). To exclude possible negative first-try effects during the immersive session, we let the participants perform all tasks once on the VR simulator as a preconditioning or warm-up session, as previously described [12]. After this regular (nonimmersive) VR simulator training, participants performed the tasks using the new IVR setup. The study was approved by the local ethics board and participants provided informed consent.

### Laparoscopic simulator

The VR laparoscopic simulator was a LapSim (Surgical Science, Gothenburg, Sweden) with Software Version 2015 and a 27″ AOC wide-screen monitor (AOC International, Taiwan). The specific hardware included the Simball 4D Joystick by G-coder Systems AB with a double footswitch (G-coder Systems AB, Västra Frölunda, Sweden).

### Simulator tasks

The simulator tasks "peg transfer," "fine dissection," and "cholecystectomy" were used for the study. The tasks combined navigational maneuvers, fine preparation, and procedural aspects; thus, they are capable of analyzing a participant's general surgical skills [12].

### Video recording of 360° operating room surroundings

A 360° camera (Samsung Gear 360, Samsung AG, Seoul, Korea) was used to record a video sequence inside the OR, including an audio recording. The setting was an artificial scenario during a laparoscopic surgery. Real members of the departments acted as the patient, two scrub nurses, laparoscopic assistant, anesthesiologist and anesthesia nurse. The scenario reflected a sequence of routine processes during a standard laparoscopic procedure.

### Video and audio signal transfer

We used a HDMI to USB 3.0 video frame grabber (Startech online®) to transfer the video output signal of the simulator to a VR-ready laptop computer (MSI; GT72VR-6RE16H51). The software development platform Unity3D® was used to integrate the simulator display into the recorded 360° OR-video. The fused environment was displayed on the VR HMD. Audio signals of the video and from the laparoscopic simulator were also synchronized and transduced by noise-canceling Bluetooth headphones (Bose® Quietcomfort® 35).

### Virtual reality head mount display

The VR display was a 2016 HTC Vive® (High Tech Computer Corp., Taiwan) with two OLED-Displays (1080 × 1200 Pixel, 90 Hz, Low-Persistence).

### Questionnaire

We used the validated motion sickness scale by Keshavarz et al. every minute during the IVR session, according to protocol [9]. The validated questionnaire by Nichols et al. [13] was used after the course to evaluate the immersion of the IVR training, as well as the effect on the participants.

### Statistical analysis

The participants' performances were evaluated based on the assessed raw items of the simulator, as well as on the calculated $z$-score, which is defined as $z=x-\mu/\sigma$, where $x$ is the raw score, $\mu$ is the mean of the parameter, and $\sigma$ is the standard deviation of the parameter. The z-scores for the singular items were sorted into three subcategories (time, handling economics, and errors) and were also added up to yield a total z-score for each task. Statistical analysis was performed using IBM SPSS Statistics 23 (IBM, Armonk, NY, USA). Performance was analyzed using the Mann–Whitney U- and Wilcoxon-signed rank tests. Data are presented as the median and interquartile range (IQR). $p$ values < 0.05 were considered significant.

## Results

The technical feasibility of the described custom IVR setup, combining a VR HMD and a VR laparoscopic simulator, was proven. The simulator tasks and metrics were successfully transferred and integrated to a highly immersive virtual 360° surrounding (Fig. 1). The total and subgroup z-scores of all three tasks did not show a statistically significant difference when comparing the regular and IVR sessions (Tables 1, 2, 3). Furthermore, laparoscopic performance in regular and IVR sessions did not differ when analyzed according to participants' experience ($p > 0.05$). The results of the simulator metrics revealed a statistically significant longer task time for fine dissection and a worse motion of the grasping instrument during IVR. A trend toward a longer task time for peg transfer was obtained in IVR. Cholecystectomy tended to be performed faster during IVR, but this difference was not statistically significant and was accompanied by a tendency toward more mistakes regarding ripped tissue and the number of liver burns. Energy was falsely applied in air or on the liver significantly longer in IVR.

Participants were exhilarated by the immersion of the VR surrounding during the IVR session and had a high impression of "being there." The generated OR-world became more realistic than the surroundings during the IVR session for most participants. Also, other (real) persons in the room became unimportant during the IVR training session, and participants paid close attention to the sounds and dialogues of the recorded OR-scenario. Questionnaire results are displayed in Fig. 2. The results of the motion sickness questionnaire revealed no sign of nausea for any of the participants at any time during the IVR session.

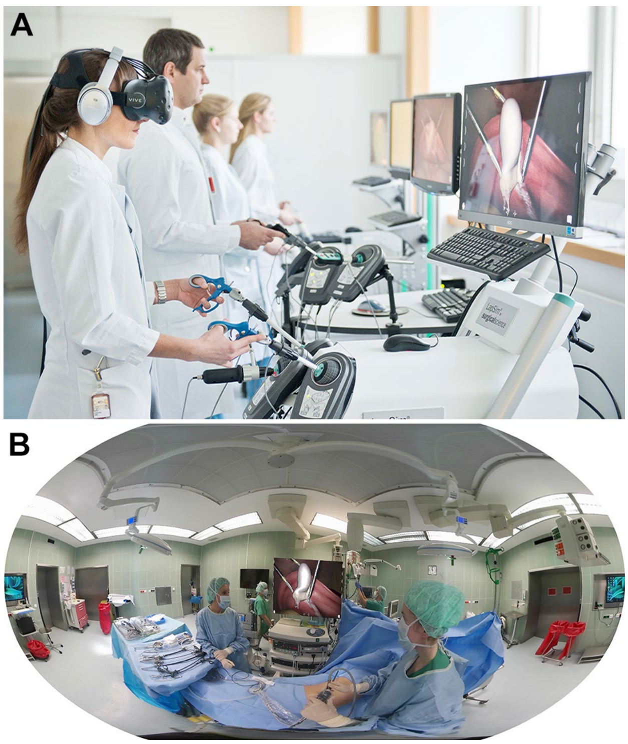


**Fig. 1** *Top* **A**: external view of the setup with regular and IVR simulations. *Bottom* **B**: personal 360° immersive operating room view of the study participant during IVR session

**Table 1** Participants' performance scores during regular and IVR laparoscopic simulation tasks: Peg transfer

| | Regular session Median (IQR) | IVR session Median (IQR) | *p* |
|---|---|---|---|
| Time (*s*) | 129.79 (111.17; 176.50) | 143.4 (122.95; 162.90) | 0.093 |
| Left time (*s*) | 27.66 (19.05; 32.62) | 34.54 (33.08; 35.73) | 0.047 |
| Right time (*s*) | 27.15 (19.58; 41.53) | 29.80 (19.07; 34.17) | 0.959 |
| *Time (z-score)* | 0.93 (−1.75; 2.41) | 0.79 (−0.18; 2.07) | 0.971 |
| Left path length (*m*) | 1.72 (1.44; 2.69) | 1.97 (1.66; 2.25) | 0.285 |
| Left angular path (degree) | 382.65 (339.98; 511.7) | 423.13 (367.12; 481.46) | 0.114 |
| Left grasps (*n*) | 7 (6; 10) | 7 (6; 9) | 0.672 |
| Right path length (*m*) | 1.85 (1.64; 2.3) | 1.72 (1.68; 1.90) | 0.333 |
| Right angular path (degree) | 378.48 (344.68; 523.11) | 379.57 (332.09; 402.50) | 0.333 |
| Right Grasps (*n*) | 8 (7; 14) | 6 (6; 7) | 0.041 |
| *Economics (z-score)* | 1.29 (−1.43; 1.57) | 0.28 (−0.10; 1.68) | 0.796 |
| Maximum drops (*n*) | 1 (0; 1) | 1 (0; 1) | 0.527 |
| *Errors (z-score)* | −0.10 (−0.10; 0.91) | 0.14 (−0.57; 0.86) | 0.912 |
| *Total z-score* | 0.93 (−1.75; 2.41) | 0.79 (−0.18; 2.07) | 0.971 |

*IQR* interquartile range, *IVR* immersive virtual reality

**Table 2** Participants' performance scores during regular and IVR laparoscopic simulation tasks: Fine dissection

| | Regular session<br>Median (IQR) | IVR session<br>Median (IQR) | *p* |
|---|---|---|---|
| Time (s) | 86.51 (62.57; 119.62) | 112.35 (82.08; 179.40) | 0.022 |
| *Time (z-score)* | 0.17 (−0.57; 0.70) | 0.25 (−0.74; 0.69) | 0.971 |
| Ripped vessels (%) | 0 (0; 66) | 33 (0; 66) | 0.257 |
| Burned vessels (%) | 3 (0; 14) | 0 (0; 3) | 0.116 |
| Ripped small vessel (%)s | 25 (0; 50) | 42 (16; 83) | 0.400 |
| Burned small vessels (%) | 66 (50; 83) | 33 (16; 83) | 0.233 |
| Burned small vessels w/o stretch (%) | 8 (0; 16) | 8 (0; 16) | 0.581 |
| *Errors (z-score)* | 0.18 (−0.31; 1.37) | −0.10 (−1.15; 1.49) | 1.000 |
| Grasper path length (*m*) | 0.33 (0.3; 0.43) | 0.57 (0.46; 0.68) | 0.007 |
| Grasper angular path (degree) | 65.69 (52.63; 84.35) | 124.02 (101.59; 132.99) | 0.007 |
| Couter path length (*m*) | 0.69 (0.54; 0.90) | 0.97 (0.73; 1.37) | 0.241 |
| Couter angular path (degree) | 114.46 (111.38; 179.02) | 176.19 (143.25; 218.53) | 0.114 |
| Grasper out of view (*n*) | 0 (0; 0) | 0 (0; 0) | 0.157 |
| Grasper out of view (*s*) | 0 (0; 0) | 0 (0; 0) | 0.180 |
| Couter out of view (*n*) | 0 (0; 0) | 0 (0; 0) | 0.564 |
| Couter out of view (*s*) | 0 (0; 0) | 0 (0; 0) | 0.593 |
| *Economics (z-score)* | 0.63 (−2.00; 2.85) | 1.06 (−4.48; 3.43) | 1.000 |
| *Total z-score* | 0.91 (−2.99; 4.40) | 0.37 (−5.52; 3.38) | 0.853 |

*IQR* interquartile range, *IVR* immersive virtual reality

**Table 3** Participants' performance scores during regular and IVR laparoscopic simulation task: Cholecystectomy

| | Regular session<br>Median (IQR) | IVR session<br>Median (IQR) | *p* |
|---|---|---|---|
| Time (*s*) | 136.83 (82.55; 163.33) | 93.06 (71.43; 155.98) | 0.333 |
| *Time (z-score)* | −0.22 (−0.73; 0.82) | 0.33 (−0.72; 0.69) | 0.739 |
| Bile Leakage (ml) | 0 (0; 12.38) | 0 (0; 0) | 0.465 |
| Liver bleeding (ml) | 3.18 (0.58; 29.26) | 10.37 (0.48; 38.20) | 0.575 |
| Energy applied in air (*s*) | 21.46 (15.62; 27.18) | 30.27 (23.35; 41.48) | 0.005 |
| Burned tissue (%) | 97.10 (90.63; 98.89) | 94.19 (82.8; 97.70) | 0.241 |
| Ripped tissue (%) | 2.90 (1.11; 9.38) | 5.81 (2.30; 17.20) | 0.241 |
| Liver burns (*n*) | 18 (10; 36) | 26 (15; 36) | 0.114 |
| Liver burns (*s*) | 8.63 (1.63; 22.17) | 14.12 (6; 28.08) | 0.013 |
| Gallbladder burns (*n*) | 3 (3; 6) | 1 (1; 10) | 0.212 |
| Gallbladder burns (*s*) | 0.36 (0.15; 1.2) | 0.37 (0.05; 1.42) | 0.260 |
| *Errors (z-score)* | 0.71 (−3.51; 3.35) | 0.57 (−3.14; 2.43) | 0.436 |
| Left path length | 0.84 (0.59; 0.89) | 0.69 (0.53; 0.87) | 0.203 |
| Left angular path (degree) | 199.3 (134.72; 239.42) | 150.53 (131.09; 184.81) | 0.203 |
| Right path length (m) | 1.29 (0.79; 2.17) | 1.16 (0.71; 1.78) | 0.646 |
| Right angular path (degree) | 297.42 (213.77; 515.50) | 263.55 (150.48; 371.95) | 0.575 |
| Left out of view (*n*) | 1 (0; 3) | 0.5 (0; 1) | 0.258 |
| Left out of view (*s*) | 1.68 (0; 11.88) | 0.44 (0; 45.90) | 0.463 |
| Right out of view (*n*) | 0 (0; 1) | 0 (0; 0) | 1.000 |
| Right out of view (*s*) | 0 (0; 4.67) | 0 (0; 0) | 0.144 |
| *Economics (z-score)* | 0.54 (−2.71; 2.07) | 1.57 (−4.87; 4.41) | 0.912 |
| *Total z-score* | 1.59 (−7.7; 2.71) | 0.86 (−10.61; 8.19) | 1.000 |

*IQR* interquartile range, *IVR*, immersive virtual reality

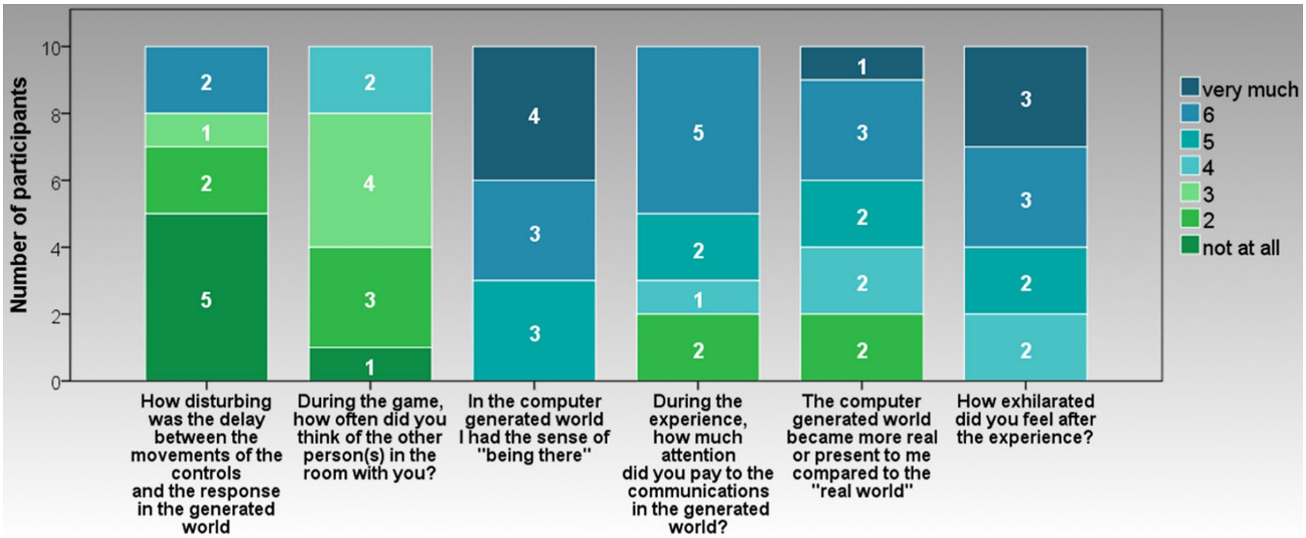


**Fig. 2** Results of the immersion questionnaire after the immersive virtual reality experience

## Discussion

Commercially available advanced VR HMDs have enriched multimedia and information technologies and have also been used for medical therapies in psychology [8]. The use of VR HMDs effectively reduces patient stress and increases patient satisfaction [14]. The increasing interest in this technology has even led to a defined ethical code regarding VR research, since negative aspects of this technology, including motion sickness and psychopathological effects, have been described [10].

In surgical training, VR HMDs have been used to create an abstract virtual OR for team training scenarios [4, 15]. No comparable highly immersive laparoscopic simulation scenario has been described so far. The only other description of laparoscopic simulation using a HMD [15] had a surrounding that was part of a virtual scenario of a simple plain room with only a 45° surrounding abstract environment. The current setup represents the latest high-end commercially available VR HMD technology in combination with an up-to-date VR laparoscopic simulator in a 360° surrounding for the first time. This approach enlarged the immersion compared with the previous study due to the display of a real OR environment using a 360° video sequence.

Task performance measurements in this first clinical setup did not influence the total z-score of the participants regardless of experience; therefore, there was equal performance regardless of immersion. The analysis of fine dissection and peg transfer task metrics revealed longer performance times during the IVR session, which may be due to distraction of the participants in the immersive setup. However, the task time results varied for fine dissection during IVR; thus, the extent of this distraction may not be the same for all participants. Subjects were faster to complete the cholecystectomy task, which may be a preconditioning effect, as previously described [12]. Yet, the number of mistakes was higher, and motion metrics were worse in IVR, supporting the distraction hypothesis that has been previously investigated with non-IVR setups [15]. The questionnaire results underline the high immersion of the custom IVR setup with high levels of presence in the generated world, exhilaration, and loss of attention to others in the room. This is an aspect that increases the attractiveness of laparoscopic simulation and may lead to more frequent use.

The lack of motion sickness during the IVR sessions may be explained by the low rate of head movements during a laparoscopic surgery, in general, compared with, e.g., VR-specific video games.

The recorded and displayed OR surrounding was familiar to all participants. This may be a reason for the high levels of exhilaration and the feelings of “being there” reported on the questionnaires. Future investigations have to compare different VR surroundings to confirm this theory.

The main limitation of the current approach is the small number of participants and the nonrandomized study design. After this first feasibility study, the analysis of learning curves to assess an impact on learning as well as skill attainment and transferability studies with larger cohorts should be the goal of future investigations regarding IVR laparoscopic simulation. Customized, interactive IVR scenarios to improve stress, and complication training have to be developed, e.g., for intraoperative bleeding complications. Mistakes on the VR simulator need to have consequences in the virtual environment. These may be influenced by means of speech, action, or text recognition. In addition, interactions with virtual characters for team training and stress training will be the next step in IVR laparoscopic simulation.

In conclusion, this first implementation of this highly immersive setup and its clinical feasibility indicate that a new attractive generation of surgical training is possible, and future investigations using IVR are needed.

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**Compliance with ethical standards**

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