Journal of Robotic Surgery (2024) 18:267
https://doi.org/10.1007/s11701-024-02018-1

RESEARCH

Immersive reality for robotic surgical training: a pilot study using 3D visors for immersive view of the operating field

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Received: 14 May 2024 / Accepted: 12 June 2024
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Abstract
Immersive intracorporeal vision is a key feature of robotic surgery, limited today to only one trainee per operation when the dual console is available. We developed a tool that provides a virtually unlimited number of surgeons with the operator's view, with the possibility to also watch the surgeon's hand movements and the operating table. In this study, we aim to assess trainees' reaction to this innovative training method. Medical students and surgery residents were offered an immersive experience with head-mounted devices, showing a didactic video in a 360° virtual space with 3D intracorporeal robotic vision, the surgeon's hand movements and the surrounding operating room during a robotic rectal resection with total mesorectal excision. Subsequently, participants were asked to fill a questionnaire evaluating the user's reaction to the new training tool including the validated System Usability Scale (SUS) and Simulator Sickness Questionnaire (SSQ), and non-validated questions. 102 participants took part in the training and the assessment questionnaires, 94 (92%) medical students and 8 (8%) surgery residents. Users' feedback was overall positive. In the engagement and intention to use items, almost 90% of the respondents voted for a complete or near complete agreement. The median SUS score was 80 [IQR 70–90]. The median SSQ score was 44.88 [IQR 22.44–82.28]. Exposing trainees to immersive robotic vision of the surgical field had a positive reaction from our audience. Our initial results encourage further implementing this technology in surgical training of medical students and residents to prove its efficacy.

Keywords Surgical training · Robotic surgery · Immersive reality · Accessibility

Introduction

A shortage of surgeons is expected in the next decades [1, 2]. Additionally, the training for the new surgeons should cover the increasingly complex new technologies [3, 4]. In fact, robotic platforms are now commonly used for elective operations, but most of the mentorship is done on a one-to-one basis, the limiting factor being the limited access to the main console. Immersive intracorporeal vision is a key feature of robotic surgery and is limited today to only one trainee per operation when the dual console is available.

We have developed a tool that provides a virtually unlimited number of surgeons with the operator's view, allowing trainees not only to see the intracorporeal movements of the instruments, but also a real-time control of the surgeon's hand movements commanding them. With immersive head mounted devices (HMDs), it is possible to showcase surgical procedures both registered or live, delivering the video signal from the robotic camera and from a camera recording the surgeon's hand movements.

This immersive tool would completely change the surgical education experience, considerably limiting costs, time and boosting accessibility.

The aim of this study is to assess medical students' and junior trainees' uptake on this new training system.

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Published online: 25 June 2024

Methods

Participants and setting

On 22nd December 2023, a workshop titled "Immersive reality for surgical training" was offered to medical students and junior trainees at Humanitas University, Pieve Emanuele, Milan, Italy. The workshop was structured with one frontal lecture on surgical training, followed by a 30 min session with Impersive (Impersive srl, Milan, Italy) immersive HMD [5].

The contents showed by visors consisted of two modules. The first was a didactic video on robotic low anterior resection (LAR) with total mesolectal excision (TME) and transanal transection with single stapled anastomosis (TTSS) [6], during which it was possible to see in a 360° virtual space the 3D robotic video, the surgeon's hand movements and the surrounding operating room (OR) (Supplementary Material, Video S1). The second was a 3D recording of the intracorporeal vision during a robotic LAR with TME. The images of the OR setting were obtained using a 360 VR 3D 8k/6k camera, while a 4k fish-eye camera mounted on the console recorded the surgeon's hand movements.

Metrics for evaluation

At the end of the immersive experience, students were asked to complete the questionnaire in [7]. The questionnaire aimed to evaluate the system by applying the first level of Kirkpatrick's four-level model of training evaluation, namely the reaction of the users to the new system [8, 9]. Reaction was categorized using 12 measures [10] (Supplementary Material Tables S1, S2). Usability was assessed with the validated questionnaires System Usability Scale (SUS) [11] and Simulator Sickness Questionnaire (SSQ) [12], while the other measures were investigated via non-validated questions. All the questions used a Likert scale ranging from 1 to 5, except the last one which was an open feedback request. The full questionnaire is available in the Supplementary Material, Table S2.

Statistical analysis

Continuous data are expressed as median and interquartile range [IQR] or as mean ± standard deviation, depending on the distribution; the distribution of all variables was assessed using the Shapiro–Wilk test of normality (with $p < 0.5$ indicating non-normal distribution). Data description and analysis were performed with Stata/SE 17.0 Software (StataCorp, College Station, TX, USA). Graphics were made with GraphPad Prism 5 Software (GraphPad Software, Inc., San Diego, California, USA).

Results

Overall, 102 participants voluntarily took part to the activity, 94 (92%) medical students and 8 (8%) general surgery residents. All the participants completed the training and the assessment questionnaires.

The Likert scale distribution of the questionnaire items are reported in Table 1: for all the training items, most of the participants expressed a positive feedback. In the motivation, engagement, and intention to use items, almost 90% of the respondents voted for a complete or near complete agreement (Fig. 1).

The usability item was composed of the SUS and SSQ scores. The median [IQR] SUS score was 80 [70–90]. The median SSQ scores reached in the Nausea, Oculomotor, and Disorientation domains were, respectively, 9.54 [9.54–38.16], 53.06 [22.74–83.38], and 41.76 [27.84–111.40]. The median total SSQ score was 44.88

Table 1 Results of the questionnaire, total answers (percentages)

Measure	Score (Likert scale 1–5)				
	Strongly agree 5	Agree 4	Neutral 3	Disagree 2	Strongly disagree 1
Affective reaction	70 (69%	28 (27%)	4 (4%)	0 (0%)	0 (0%)
Quality of instruction or feedback	43 (42%)	34 (33%)	19 (19%)	6 (6%)	0 (0%)
Realism and presence	67 (66%)	30 (29%)	5 (5%)	0 (0%)	0 (0%)
Motivation	73 (72%)	21 (21%)	6 (6%)	2 (2%)	0 (0%)
Usability	Figure 2				
Perceived learning effectiveness	73 (72%)	23 (23%)	4 (4%)	1 (1%)	1 (1%)
Subject comparison	66 (65%)	27 (26%)	7 (7%)	1 (1%)	1 (1%)
Engagement or interactiveness	59 (58%)	25 (25%)	13 (13%)	5 (5%)	0 (0%)
Intention to use	77 (75%)	21 (21%)	3 (3%)	1 (1%)	0 (0%)
Confidence level	62 (61%)	35 (34%)	4 (4%)	1 (1%)	0 (0%)

[22.44–82.28] (Fig. 2). Almost 33% of the participants experienced mild and moderate eyestrain symptoms (Fig. 3).

Users' feedback was overall positive; people with spectacles did not have issues wearing the HMDs, and three users would have preferred to be able to adjust the interocular distance. The main suggestion was to adjust the positioning of the videos in the 3D virtual space to keep the head more relaxed.

Discussion

While robotic-assisted surgery is increasingly used for abdominal operations, a gap exists between the spread of the technique and the trainee's exposure to this technology [13]; in particular in Italy, where a structured robotic curriculum does not exist yet. Skill transfer from laparoscopy is limited [14, 15] and, as for now, just one mentee has the same vision of the operator by using the second console. Furthermore, when the second console is available, priority to take that spot is rightly given to senior residents and junior staff surgeons for them to be proctored by senior operators.

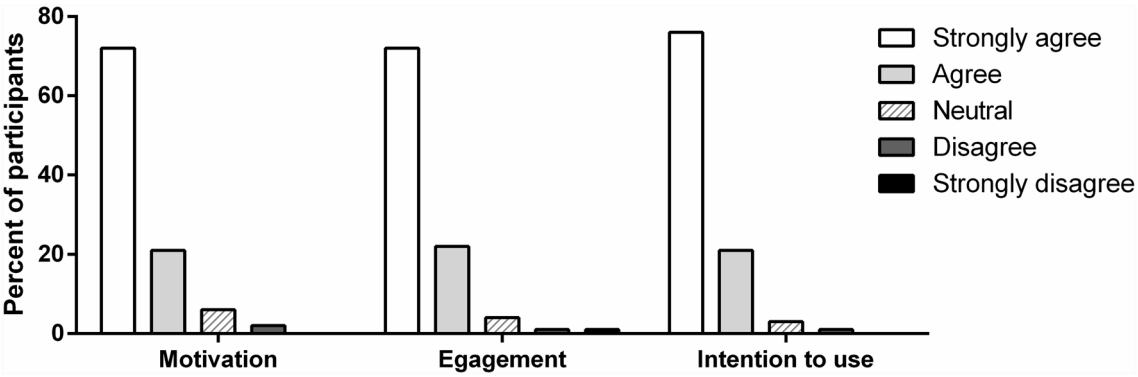


Fig. 1 Questionnaire results for motivation, engagement, and intention to use measures

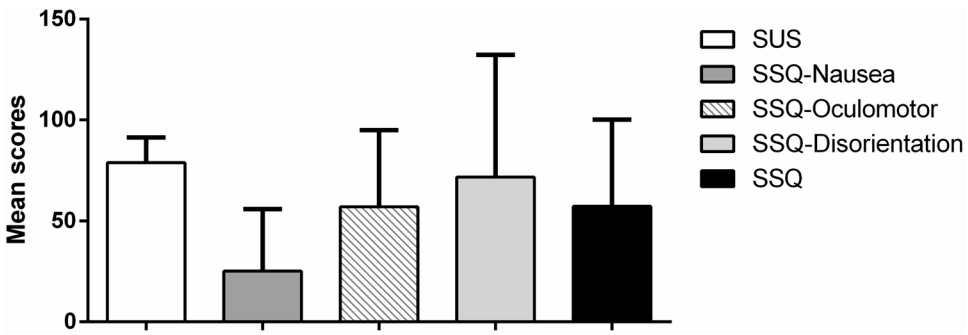


Fig. 2 System UsabilIty Score and Simulation Sickness Questionnaire results. *SUS* Sistem Usability Score, *SSQ* Simulation Sickness Questionnaire

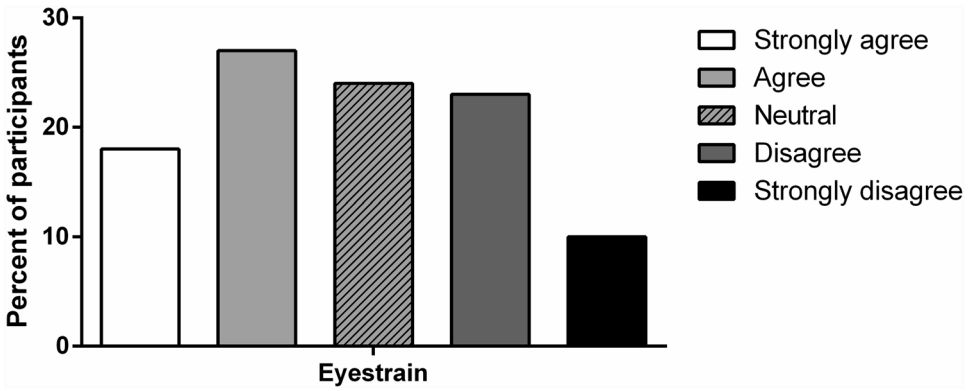


Fig. 3 Presence of eyestrain in visor users

Consequently, students and junior residents are left out from an important training possibility.

In surgery, watching means learning, "stealing with your eyes". In the past that meant that observers crowded behind the surgeons during open operations, while the advantage of laparoscopy is that anyone in the OR can have the same vision. On the contrary, we have the impression that during robotic surgery, many training occasions are lost, because of limited access to the operating field. We propose to use a relatively simple, portable, and inexpensive technology to contemporarily deliver the 3D view of the operating field to a larger number of trainees. Immersive reality (IR) has already proven to be effective and well received by students and residents [16, 17]. During robotic surgery, the advantage of having the first operator's view of the surgical field consists in seeing in the most detailed way; furthermore, the cognitive load appears to be lower if the procedure is viewed from a first-person perspective [18].

Overall, 102 participants took part in the elective activity, mostly medical students ($n = 94$, 92%), but also residents interested in the usability of the technology for their training. We chose to include both students and surgical residents to have feedback from subjects with different exposures to surgical procedures; unfortunately, there was little adhesion to the initiative from surgery residents. Our intention would be to use the technology both for students and for residents since the same operation can be appreciated at different levels of experience [19]. Students can appreciate the in vivo anatomy and get familiar with surgical procedures. On the other hand, residents can observe the surgical steps and the dissection planes at the highest quality possible. Furthermore, the system finds application also in the training of expert surgeons who are already familiar with robotic techniques and seek to enhance their proficiency in specific procedures.

Medical students regardless of their seniority and intention to pursue a surgical career were included. This makes our cohort heterogeneous, but in line with our primary aim that was to assess a potential trainee's reaction to the system. What, however, can be seen as a limitation of this proof-of-concept study is the limited proportion of surgical residents in the cohort. Undoubtedly, now that we have recorded positive reaction from the audience involved, a specific study regarding usability and utility specifically in surgical residents and experienced surgeons is needed to investigate the full potential of our solution.

The added value of the proposed technology is, especially for more experienced trainees, the possibility to also see the real-time surgeon's hand movements and the operating table, just moving the head in the 360° or 180° virtual space (Video S1). Therefore, IR visors for robotic training can confer to the trainee a thorough knowledge of robotic surgery techniques not only from the console point of view, but also regarding the management of the operating table: from trocar positioning and assisting, to managing eventual robotic arm conflicts. Interestingly, users agreed on the added value that this technology could have compared to standard training. The results obtained from the questionnaire encourage further implementation of this technology alongside OR training and prove its utility.

As far as we know, there are no other comparable solutions currently on the market. The huge limitation in current virtual reality (VR) robotic simulators is the lack of a realistic intracorporeal vision. Solutions like Immertec [20] allow immersive view of the OR, but not of the immersive vision of the operating field and are dependent on a specific streaming hardware. Our solution is completely independent of the streaming hardware and applicable to different robotic systems on the market. Furthermore, thanks to the full-custom app, it can be used with any VR visor (e.g., Pico, Quest, Vision Pro).

One of the main aims of our study was to demonstrate that current and future trainees would be interested in the usage of a 3D visor for their surgical training. Based on the gathered answers on the questionnaire, we can postulate that that the next generation of medical doctors and surgeons is enthusiastic about this idea, showing a high level of motivation, engagement in the technology, and intention to use it (Fig. 1).

Surgeries being hours long, it is fundamental that the visor does not cause any discomfort. For this reason in our study, we administered to participants the validated SUS and SSQ questionnaires [11, 12]. The results were overall positive as reported in Fig. 2. It must be noted, however, that the participants in our study used the HMD for a time span of 30 min instead of the hours required to perform an operation, and for this reason our results may be biased. However, considering the overall extremely positive answers, it can be deducted that probably wearing the device for a longer time would not lead to opposite conclusions. People with visual impairments compensated with spectacles were able to use the HMD without the need to remove the eyeglasses.

A significant proportion of participants reported a degree of eyestrain while using the system (Fig. 3). This is probably the most relevant drawback of the current technology, which nevertheless could be solved by implementing the distance between the camera and the object.

We have not performed a cost analysis, but intuitively we can say that the costs are a few hundreds of euros for the HMDs and an initial investment to create a library of procedures. The technology would then be available for trainees anytime unlimitedly.

This system has the intrinsic possibility of real-time streaming of operations. Streaming of live surgeries has the further advantage of real-time interaction between the operator and trainees. In the prospective of a progressively

more digital training environment, real-time streaming of operations via IR visors could be implemented also in the training programs of medical students and surgical residents. This solution meets the need to train an increasing number of surgeons in complex procedures, overcoming the limits of the current resources available.

Conclusions

In conclusion, exposing trainees to immersive robotic vision of the surgical field had a positive reaction from our audience. Our initial results encourage to further implement this technology in surgical training of medical students and residents to prove its efficacy.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11701-024-02018-1.

Author contributions Antonino Spinelli conceived the technique and the paper. Antonino Spinelli, Carlotta La Raja, Michele Carvello, and Caterina Foppa concieved the methods. Antonino Spinelli, Carlotta La Raja, Michele Carvello, and Riccardo Patti performed material preparation and conducted the didactic activity. The first draft of the manuscript was written by Carlotta La Raja, Michele Carvello, and Annalisa Maroli, and all authors commented on previous versions of the manuscript. All authors read and approved the published version of the manuscript.

Funding No funding was received to assist with the preparation of this manuscript.

Data availability Data supporting the reported results are protected and access can be obtained under request.

Declarations

Conflict of interest AS acted as a speaker/consultant for Johnson&Johnson and Stryker. MC acted as a speaker for Takeda and Pfizer. CLR, RP, CF, and LS declare that they have no conflict of interest.

Ethical approval This study was performed in line with the principles of the Declaration of Helsinki. The IRCCS Humanitas Research Hospital Ethics Committee has confirmed that no ethical approval is required.

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