

Validation of the ViGaTu Immersive Virtual Reality Endoscopy Training System for Physicians and Nurses

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ABSTRACT

Background & Aims: Endoscopy simulators are primarily designed to provide training in interventions performed during procedures. Peri-interventional tasks such as checking patient data, filling out forms for team time-out, patient monitoring, and performing sedation are often not covered. This study assesses the face, content, and construct validity of the ViGaTu (Virtual Gastro Tutor) immersive virtual reality (VR) simulator in teaching these skills.

Methods: 71 nurses and physicians were invited to take part in VR training. The participants experienced an immersive VR simulation of an endoscopy procedure, including setting up the endoscopic devices, checking sign-in and team time-out forms, placing monitoring devices, and performing sedation. The actions performed by the participants and their timing were continuously recorded. Face and content validity, as well as the System Usability Scale (SUS), were then assessed.

Results: 43 physicians and 28 nurses from 43 centers took a mean of 27.8 min (standard deviation $\pm$ 14.42 min) to complete the simulation. Seventy-five percent of the items for assessing face validity were rated as realistic, and 60% of items assessing content validity and usefulness of the simulation for different learning goals were rated as useful by the participants (four out of five on a Likert scale). The SUS score was 70, demonstrating a high degree of usability. With regard to construct validity, experienced endoscopy staff were significantly faster in setting up the endoscope tower and instruments than beginners.

Conclusions: This multicenter study presents a new type of interdisciplinary endoscopy training system featuring peri-interventional tasks and sedation in an immersive VR environment.

Key words: virtual reality – endoscopy – training – simulator – education.

Abbreviations: ERCP: endoscopic retrograde cholangiopancreatography; SUS: System Usability Scale; ViGaTu: Virtual Gastro Tutor; VR: virtual reality.

INTRODUCTION

At present, endoscopic training is mainly based on an apprenticeship model [1], with learners being trained under supervision by experienced endoscopists. Endoscopic training is consequently considerably limited by the time available, the instructor's educational skills, the variety of diseases treated in the center concerned, and by patient safety considerations. Many simulators have been developed in recent years to extend training beyond

these limitations [2, 3]. However, due to high acquisition costs, endoscopic computer-based simulators are rare in clinical practice and are mostly used in endoscopic courses or shared by more than one institution [4-6]. They also require the presence of a supervisor, which may be not cost-effective [7].

In general, medical simulators should provide learners with a controlled environment that includes real clinical cases [8]. They should also allow the learner to interact with the environment and to acquire medical skills without any risk to patients [9]. Simulators have been reported to be highly effective in recent years in relation to improving patient-related outcomes [6, 10]. Numerous virtual reality endoscopic simulators aimed at improving training have therefore been introduced [6]. However, most simulators focus on a single intervention – for example, gastroscopy, colonoscopy, or endoscopic retrograde cholangiopancreatography (ERCP) [6, 11, 12], and this

does not reflect the complexities of clinical reality. Peri-interventional activities such as filling out pre-interventional checklists and attaching the patient's monitoring devices (including a blood pressure cuff and pulse oximeter) play an important role in everyday clinical routine and have a substantial impact on the outcome for patients [13]. Studies in the field of surgery have shown that checklists in particular can prevent mistakes [14-16]. In 2009, a worldwide multicenter study provided evidence that a World Health Organization checklist can significantly reduce the rates of severe complications, infections, and even mortality [17]. Checklists such as "team time-out" protocols are also considered useful in endoscopy, especially for team communications, and are recommended by the guidelines, as is patient monitoring during sedation [13, 18-22].

The complex interaction between physicians and nurses is also not reflected in most simulators. Physicians and nurses in endoscopy departments work as a team in preparing the endoscopy room and checking on the indication, availability, and functionality of endoscopic devices [21, 22]. It is therefore necessary for both physicians and nurses to have an understanding of all the important steps.

The introduction of inexpensive consumer-grade immersive virtual reality (VR) head-mounted displays in recent years has made it possible to simulate complex environments and procedures in a location-independent manner [23]. VR also provides an opportunity to incorporate structured curricula and complex simulations into endoscopy training.

In a collaborative venture including physicians and nurses specialized in endoscopy, as well as media educators and computer scientists, we have therefore developed a VR simulator called "ViGaTu" as part of a publicly funded project. The aim was to create an open source VR simulator which, in addition to colonoscopy, can also provide training in peri-interventional skills in particular, independently of time and location. To evaluate the use of the current version of ViGaTu, a multicenter study including 71 physicians and nurses was conducted to assess the system's usability as well as its face, content, and construct validity.

METHODS

Survey Instruments

To assess face validity, a 20-item questionnaire was used in which the participants were asked to rate how realistic they found the different components of the immersive VR simulation system to be (Supplementary file, Table I). A 10-item questionnaire was used to assess content validity (Supplementary file, Table II). This questionnaire examined how useful the participants found the VR simulation to be for several tasks in the setting of endoscopy. Agreement with the items in both questionnaires was rated on a five-point Likert scale, with 1 representing full disagreement and 5 representing full agreement. The System Usability Scale (SUS), consisting of 10 items, was used to assess usability [24]. Demographic information and data on the participants' prior endoscopic experience and VR experience were also collected.

Participants

Seventy-one participants from 29 cities in Germany, representing 43 centers, were invited and took part in the study from September 14 to September 23, 2022. Forty-three of the participants were working as physicians and 28 as nurses in endoscopy. The participants were classified either as beginners or as experienced practitioners. The allocation criteria for the group of experienced practitioners were: at least 4.5 years' work experience or more than 200 completed endoscopies for physicians, and at least 3.5 years' work experience or more than 200 assisted endoscopies for nurses.

Simulator

The Meta Quest 2 system (Meta Platforms, Inc., Menlo Park, California, United States) was used to present the simulation. The system consists of a head-mounted display and two handheld manual controllers. The virtual environment was created using Unity 3D (Unity Technologies, San Francisco, California, United States). Most of the 3D elements were designed in collaboration with Threedee (ThreeDee GmbH, Munich, Germany). In the virtual environment, the participants were able to carry out several tasks that are essential for peri-interventional procedures or for colonoscopy itself. Interaction in the immersive VR environment was performed using controllers that allowed participants to pick up equipment and place it in the correct position, for example. In addition, the participants were able to move freely in the virtual endoscopy room by walking or by "teleporting" to a different place in the room using the controllers. The developed framework of ViGaTu is open source and can be downloaded from <https://github.com/virtual-gastro-tutor/vigatu>.

Study Design

This is a prospective single-arm study. After completing a VR-based tutorial in order to familiarize themselves with the immersive simulator and usage of the controller functions, the participants experienced a simulation of an endoscopy procedure. In VR, they were able to perform relevant steps such as assembling the endoscope tower and performing checklists such as a team time-out, or sedating the patient. The Video Supplement demonstrates the key elements of the immersive VR simulation. All of the actions performed by the participants and the timing of them were recorded by the ViGaTu software during the simulation. Afterwards, the participants completed a questionnaire including a total of 55 questions.

Statistical Analysis

Statistical analysis was performed using the R statistics program (version 4.2.1). All significance tests were performed with $\alpha = 0.05$, unless Bonferroni correction was necessary due to multiple hypothesis testing. Wilcoxon rank sum tests were conducted to test for differences between the two groups of experienced endoscopy staff and beginners.

Ethics

Ethical approval for the study was obtained from the local research ethics committee at the University of Würzburg. Informed consent was obtained from all of the participants prior to participation.

RESULTS

Baseline Characteristics

The participants consisted of 43 physicians and 28 nurses, among whom 73.3% were considered experienced and 26.7% beginners (Table I). They were working in 43 different centers in 29 cities in Germany. Most of the centers were university hospitals (50.7%) or community-based hospitals (43.7%). Most of the participants had no previous experience with VR (73.7% of the beginners and 75.0% of the experienced practitioners).

There were significant differences ($p < 0.001$) between experienced participants and beginners with regard to age, general work experience in years, and years of work experience in endoscopy.

All of the participants set up the endoscope tower and instruments (Fig. 1), placed the monitoring devices (e.g., pulse oximeter, blood pressure cuff), and went through checklists such as sign-in and team time-out (Fig. 2), as well as implementing the sedation. Most recent English version of simulator is presented in the video available at <https://fex.ukw.de/public/download-shares/g5rbNNZti72zonYsFvJ0u1bafqJmj8EO>. The participants also experienced a colonoscopy examination displaying the identification and resection of multiple polyps, after which they had to document the final polyp count.

Face Validity

Evaluation of the face validity showed that 75% of the items were rated with a mean of above 4.0 on the 5-point Likert scale, indicating a high level of agreement that the component covered by the item was represented realistically in the VR simulation. Fig. 3 shows the means and standard deviations (SD) for the rating of the 20 items assessing face validity. Detailed values are presented in Supplementary file, Table I. The best-rated components were the representation of the endoscopy room (mean 4.47, SD 0.92) and endoscope tower (mean 4.41, SD 1.06), and the lowest-rated components were the representation of the patient's state of consciousness (mean 3.78, SD 1.22) and placement of the peripheral venous access

(mean 3.68, SD 1.39). The overall realism of the simulator was rated with a mean of 4.07 (SD 0.89). For all 20 items, there were no significant differences ($\alpha = 0.0025$ with Bonferroni correction) in the ratings given by beginners and experienced participants.

Content Validity

The ratings for the items assessing the general usefulness of the simulator as well as the best-rated and two lowest-rated items are shown in Fig. 4. The full data, including all items and exact means and standard deviations, are given in Supplementary file, Table II. As with face validity, the survey of content validity was conducted using a Likert scale (rating 1–5).

The VR simulation was perceived to be most useful for learning standardized lists such as the sign-in (mean 4.49, SD 0.84) and for learning to identify the necessary equipment (mean 4.25, SD 0.98). It was perceived as least useful for learning to deal with sedation complications (mean 3.62, SD 1.30) and for recognizing and reducing complications (mean 3.61, SD 1.14). The ratings for the 10 items did not differ significantly ($\alpha = 0.005$ with Bonferroni correction) between beginners and experienced participants. Among the 10 items assessing content validity, 60% received a mean rating of more than 4.0. Seventy-six percent of the participants gave a rating of 4 or 5 points on the 5-point Likert scale for their level of agreement with the statement that they would recommend the simulator.

Overall, the usability of the simulator was rated with a mean of 70 points on the SUS (0–100).

In the qualitative evaluation, participants made many positive comments. These included how realistic the VR environment appeared and the detailed and easy to understand step-by-step descriptions for each task. They valued the software as an opportunity to train in a safe environment and encouraged the study team to continue working on it. They were critical of the disappearance and reappearance of objects after interaction in the virtual environment, and that in reality the blood pressure cuff and pulse oximeter would not be attached to the same arm at the same time.

Table I. Characteristics of the participants

Characteristic	Beginners	Experienced	p
Age in years, median (95 % CI)	27.0 (23 - 30)	41.5 (38.0 - 44.0)	< 0.001
Gender			
Male, n (%)	12 (63.2)	32 (61.5)	
Female, n (%)	7 (36.8)	20 (38.5)	
Profession			
Physician, n (%)	11 (57.9)	32 (61.5)	
Nurse, n (%)	8 (42.1)	20 (38.5)	
Institution			
University hospital, n (%)	11 (57.9)	25 (48.1)	
Community hospital, n (%)	6 (31.6)	25 (48.1)	
Other, n (%)	2 (10.5)	2 (3.8)	
Work experience, years; median (95% CI)	2.0 (0 - 3)	14.5 (12.0 - 17.0)	< 0.001
Endoscopy experience, years; median (95% CI)	0.0 (0.0 - 0.5)	8.0 (6.0 - 12.0)	< 0.001
No VR experience, n (%)	14 (73.7)	39 (75.0)	

CI: confidence interval; VR: virtual reality.



Fig. 1. Examples of the manual tasks of setting up the endoscope (left) and turning on the different devices on the endoscope tower (right). The insert in the lower left corner represents the view of the participant from outside.

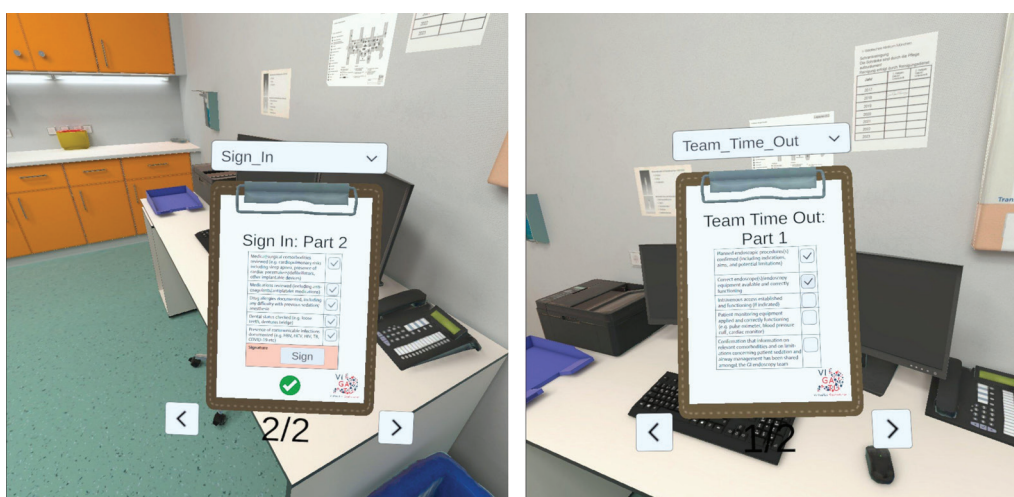


Fig. 2. Examples of the tasks included in the sign-in form (left) and team time-out form (right).

Construct Validity

The participants spent a mean of 27.82 min (SD 14.42 min) in the VR simulation. Due to a lack of normal distribution after the participants had been divided into beginners and experienced practitioners, the median was used for the subsequent analyses. The time spent in VR did not differ significantly between experienced participants (median 25.49 min) and beginners (median 25.53 min; $z = -0.82$; $p = 0.42$). However, participants with experience in endoscopy took significantly more time to explore the endoscopy room before starting the tasks than beginners (beginners, median 30.12 s; experienced participants, median 42.18 s; $z = 2.18$; $p < 0.05$), presumably identifying items needed for the tasks to come. In addition, experienced endoscopy staff needed less time than beginners to set up the endoscope tower and instruments (median 117.63 s versus median 150.42 s; $z = -2.58$; $p < 0.01$) and they were also significantly faster in turning on each device on the endoscope tower (median 64.37 s versus median 109.28 s; $z = -3.04$; $p < 0.01$) (Fig. 5).

DISCUSSION

Traditionally, endoscopy training uses an apprenticeship model. Due to limitations such as the instructor's available time and patient safety, the training is often supplemented using conventional simulators. In view of the high costs and low level of complexity of the clinical cases with conventional simulators, VR simulators with head-mounted displays may be an inexpensive and location-independent alternative. In a collaborative venture including physicians and nurses with experience in endoscopy as well as media educators and computer scientists, we therefore developed the open source ViGaTu VR simulator in a publicly funded project. The aim was to provide training in peri-interventional procedures (such as completing sign-in and team time-out checklists), as well as in propofol sedation and endoscopy. To evaluate the use of the current version of the simulator, we conducted a multicenter study involving 71 physicians and nurses and assessed the SUS as well as the face, content, and construct validity.

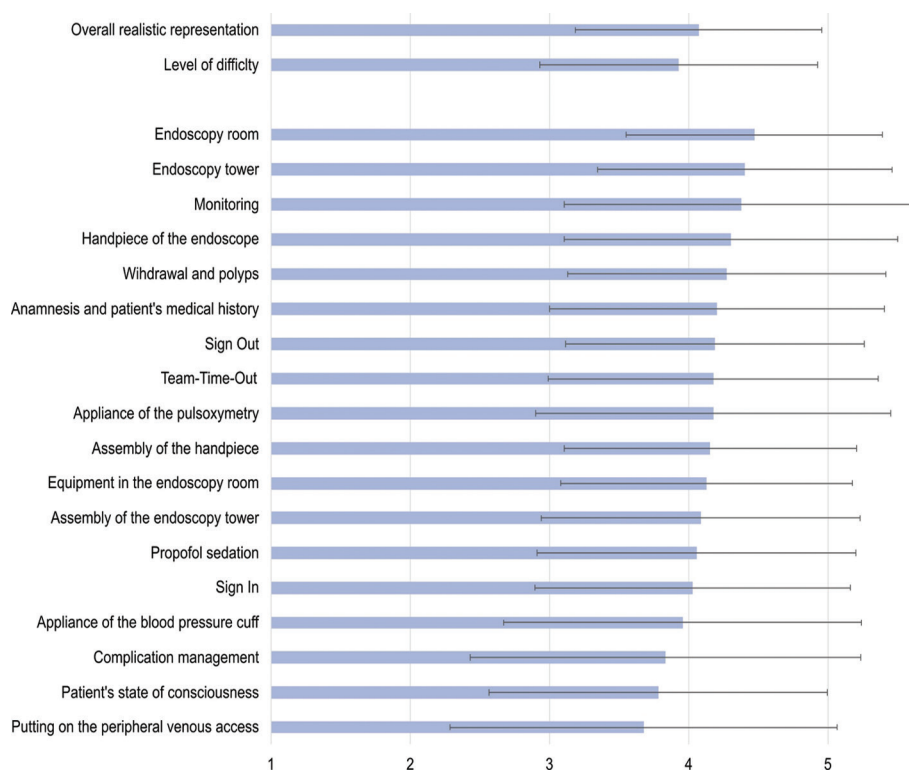


Fig. 3. Face validity. Five-point Likert scale (1, fully disagree to 5, fully agree). Values are presented as means with standard deviation.

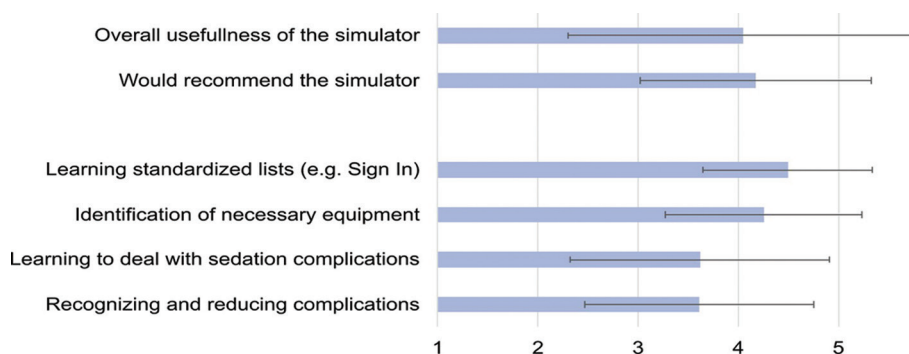


Fig. 4. Content validity. Excerpt from the questionnaire. Five-point Likert scale (1, fully disagree to 5, fully agree). Values are presented as means with standard deviation.

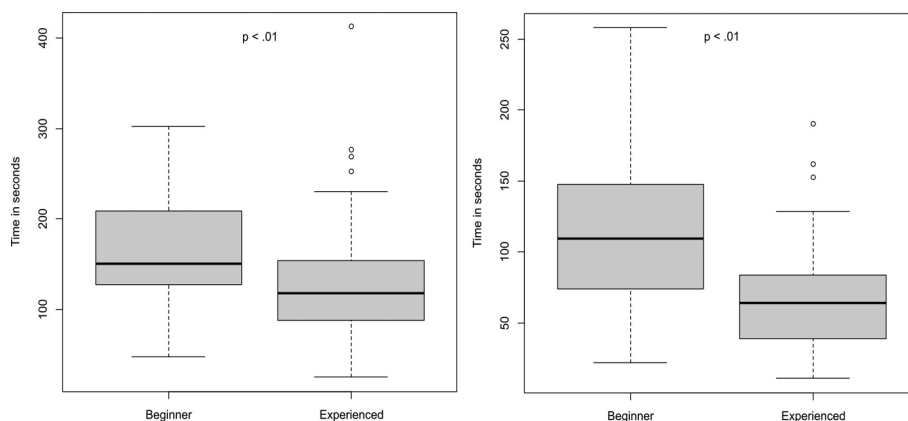


Fig. 5. Construct validity. Left chart represents the time taken to set up the endoscope tower and instruments. Right chart represents the time taken to switch on each device on the endoscope tower. Values are displayed as box and whisker plots representing the median, the maximum and minimum time needed.

The questionnaire survey conducted showed that the VR simulator was well accepted and recommended by experienced endoscopic staff and beginners from 43 different centers. Seventy-five percent (15 of 20 questions) of the face validity aspects were given ratings of at least 60% of the maximum Likert score by all participants – indicating the high degree of realism of the simulator, which is comparable with other conventional and VR-based simulators, which have results ranging from 60% to 92% [8, 25, 26]. In particular, the overall representation and the depiction of the endoscopy room and endoscope tower were rated as realistic by all of the participants. Realistic representation of the VR environment as well as the patient's case is indispensable for immersion of the participant. In other comparable studies, such as the Operation Room Fire Virtual Training Simulator and the Virtual Transluminal Endoscopic Surgery Trainer presented by Dorozhkin et al. [25, 27], the realism of the overall presentation was rated at 3.0–3.5 out of 5 points on the Likert scale. The rating of 4.1 for the overall representation obtained in the present study is therefore high in comparison, indicating that the current version of ViGaTu is already close to reality. Only the representation of the patient's state of consciousness and placement of the peripheral venous access received lower ratings. A review of the detailed comments in the survey showed that in particular, placing the propofol injection at a 90° angle to the peripheral venous access and placing the venous access on the same arm as the blood pressure cuff led to a low ranking in the questionnaire. These maneuvers were initially implemented in order to allow easier access to the propofol injection, but will be corrected accordingly in an updated version of the simulation.

With regard to the results for the content validity items, the highest scores were given for the evaluation of standardized peri-interventional lists and identification of necessary equipment. The importance of these peri-interventional measures is underlined by the national and international guidelines [13, 17, 20]. The participants assessed the VR simulation on learning how to deal with sedation complications and how to recognize and reduce such complications as at least useful, but still above average — which is not surprising, since this current version of the simulator did not offer an option for treating complications. However, the option has already been implemented in an updated version. The update includes among other things options for treating hypotension by administering intravenous fluids and for treating hypoxia with a nasopharyngeal tube or using bag–valve–mask ventilation.

Evaluation of the SUS score as an indicator of the usability of VR simulations showed a value of 70. The ViGaTu system thus has a high level of usability and is superior to earlier VR simulators, with scores ranging from 64.03 to 67.17 [28, 29].

The construct validity was also evaluated in order to identify possible differences between experienced participants and beginners. For this purpose, the time taken for different sections of the simulation was measured. The construct validity showed that the total time spent in the VR simulation did not differ between experienced practitioners and beginners (median for experienced participants 25.49 min, median for beginners 25.53 min). While experienced participants spent significantly more time exploring the endoscopy room before starting the tasks, they were significantly faster in setting up the

endoscope tower and instruments, as well as in switching on the endoscope tower, in comparison with the beginners. These results show that the simulator can distinguish adequately between experienced participants and beginners, indicating a sufficient level of difficulty. The fact that the experienced participants spent more time in the endoscopy room before starting the simulation might indicate an effort to locate important instruments in order to successfully perform the tasks. However, as the current version of the VR headset does not provide eye-tracking technology, it is difficult to confirm this hypothesis. Further investigation, with acquisition of additional data such as eye-tracking and pupil dilation, is needed in order to provide more insight into the interaction between participants and the virtual environment.

As the current version of ViGaTu is not the final one, as mentioned above, the simulator and the present study still have certain limitations: it was not possible to treat complications in the current version, but this will be implemented in further releases. The studied version of the simulator also offered only one language (German). We have therefore implemented a translation module that lists all of the audio files and texts that are in use. We used this module after the completion of this study to translate the simulator into English, as shown in the figures and the accompanying video. The simulator can now be translated into more languages. In addition, simulators such as the one presented here are static programs that only reflect the current state of guidelines and knowledge. In order to help implement updates and adapt to national guidelines, we published the framework of ViGaTu as an open source. Additionally, we created a new set of 3D assets that are published with the software as open educational resources (OER). This will help further improve ViGaTu and its applications.

The great advantage of the VR simulator is that it can be very close to reality by simulating fully immersive scenarios from the moment the patient is welcomed to discharge. These scenarios can be varied by using patient cases with different medications and medical histories. Not only can the patients vary, but different clinical scenarios can also be implemented, such as the management of sedation related complications. VR has the advantage of simulating the environment with simultaneous events. This is in contrast to other simulation media. During a screening colonoscopy, events of an endoscopic nature can occur simultaneously with events related to the sedation. In these cases, the trainee must decide which event to react to first and when the regular examination can be continued.

Future plans for our open source simulator include incorporating more clinical cases that are relevant to trainees. These can be graded, so that learners can choose the level of difficulty they want. The next step will be to incorporate a more sophisticated endoscopic simulation with basic and advanced endoscopic procedures. Again, the simulator will aim to provide important theoretical background to the procedure, such as the specific risks associated with each resection technique.

As previously reported by Grover et al., simulation-based training accompanied by a structured comprehensive curriculum translate better into clinical success than self-regulated learning [30]. However, most of the current

simulators mainly provide an endoscopic intervention without a structured curriculum. In our project, guideline-based knowledge will therefore be conveyed to learners using e-learning-based lessons completed before they start using ViGaTu. The multiple hours lasting e-learning lessons, which were not evaluated in this study due to time constraints, are designed to allow trainees to learn at their own pace, regardless of location and time.

CONCLUSIONS

To the best of our knowledge, this is the first open source VR-based endoscopic simulator that integrates peri-interventional procedures alongside the endoscopic intervention, as well as propofol sedation. The simulator was considered realistic and useful by both experienced endoscopy staff and beginners. The simulator was able to distinguish between experienced participants and beginners. The majority of the participants would also recommend ViGaTu for endoscopic education. Limitations such as the absence of complication management and multilanguage support are already implemented and will be evaluated in future studies.

Conflicts of interest: None to declare.

Authors' contribution: A.H., D.H., M.E., V.R. conceived and designed the study. D.H. and M.E. collected data. A.H., D.H., M.E., E.W., V.R., J.K. performed the statistical analysis, interpreted the data, and drafted the manuscript. D.H., M.E., J.K., V.R., E.W., A.M., T.S., T.R., S.D. and A.H. critically revised the manuscript, approved the final version to be published, and agree to be accountable for all aspects of the work.

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