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Development and evaluation of a trauma decision-making simulator in Oculus virtual reality

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A B S T R A C T

Background: Consumer-available virtual-reality technology was launched in 2016 with strong foundations in the entertainment-industry. We developed an innovative medical-training simulator on the Oculus™ Gear-VR platform. This novel application was developed utilising internationally recognised Advanced Trauma Life Support (ATLS) principles, requiring decision-making skills for critically-injured virtual-patients.
Methods: Participants were recruited in June, 2016 at a single-centre trauma-course (ATLS, Leinster, Ireland) and trialled the platform. Simulator performances were correlated with individual expertise and course-performance measures. A post-intervention questionnaire relating to validity-aspects was completed.
Results: Eighteen(81.8%) eligible-candidates and eleven(84.6%) course-instructors voluntarily participated. The survey-responders mean-age was 38.9($\pm$11.0) years with 80.8% male predominance. The instructor-group caused significantly less fatal-errors ($p < 0.050$) and proportions of incorrect-decisions ($p < 0.050$). The VR-hardware and trauma-application's mean ratings were 5.09 and 5.04 out of 7 respectively. Participants reported it was an enjoyable method of learning (median-6.0), the learning platform of choice (median-5.0) and a cost-effective training tool (median-5.0).
Conclusion: Our research has demonstrated evidence of validity-criteria for a concept application on virtual-reality headsets. We believe that virtual-reality technology is a viable platform for medical-simulation into the future.

1. Background

Virtual reality headsets: are they more than entertainment?

Not since the advent of the smart-phone have we been so transfixed by a technology that engrosses our visual and acoustic senses, with tens of billions in predicted revenue.[1] The new Virtual Reality (VR) technology has the ability to potentially capture the attention of even the most technologically naive. The unprecedented degree of immersion may appeal to all ages. But is medicine ready for this virtual-reality revolution?

The “Ultimate Display” was conceptualized in 1965 by Ivan Sunderland, an American scientist. Sunderland elaborated on this: “A display connected to a digital computer gives us a chance to gain familiarity with concepts not realisable in the physical world” and “Concepts which never before had any visual representation can be shown”.[2] Through contributions from Harvard University and Massachusetts Institute of Technology (MIT) the ‘Sword of Damocles’ became a reality in 1968: unwieldy spectacles with two cathode-ray-tubes provided a 40-degree field of vision in a primitive virtual space.[3]

Affordability is one of the major precipitators of this virtual renaissance. The technology was previously confined to high-fidelity laboratories, with narrow fields of vision, high latency and low frame rates. The comfortable Oculus VR (LLC, California, United States) Head-Mounted Display (HMD) provides users an evolution in visually immersive experiences: a >96-degree field-of-view,

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minimum weight of 318 g and improved performance.[4–6] Revived largely by the entertainment industry, Oculus has released this technology via smartphone (Samsung Electronics) and PC-compatible headsets (Oculus Rift), with HTC (New Taipai, Taiwan) and Sony (Tokyo, Japan) versions also available.

Therapeutic applications of VR headsets amongst patient populations are becoming apparent, particularly in bio-psychosocial models of cognitive diseases. The immersive qualities permit avoidance of real-world stressors while eliciting real physiological responses from within the virtual environment.[7] Established VR applications in disease states include: exposure therapy for anxiety disorders through desensitization[8,9] and easing delusional disorders by VR cognitive therapy.[10] VR has been shown to provide distraction therapy and analgesic properties for burn-victims and oncology patients.[11,12] Similarly, it can relieve patient anxiety during a local anaesthetic procedure (Perpetuo-Socorro hospital, Alicante).[13] As an assessment tool, it has been adopted for 'Falls risk' profiling amongst glaucoma sufferers.[14]

The adoption of VR Headsets in medical training has been negligible despite perceived strengths such as "cueing stimuli to support error free learning."[15] Recent military advances provide army-medics a VR simulator for prioritising health needs and a realistic cognitive workload of challenges in a virtual environment.[16,17]

Several applications as a diagnostic and visualisation platform are emerging in healthcare: Intraoperative use of augmented-reality has aided in interventional cardiology.[18] VR digital pathology allows navigation and interpretation of patient slides.[19] The first 360-degree live operation was recently streamed from The Royal London Hospital, UK.[20] Other proof-of-concept applications include: pioneering preoperative-planning of a congenital heart defect using 3D-reconstructed imagery (Nicklaus Children's Hospital, Miami)[21] or pelvic-floor anatomy visualisation via CAVE VR environments.[22] In the field of Gerontology the development of innovative projects such as "We are Alfred" (An award winning VR venture providing a virtual patient's perspective) will undoubtedly encourage clinicians in the field to enhance empathy and understanding of the aging process.[23]

In the setting of technology-enhanced-learning we may see further benefits in multimodal blending with active learning through experience, as theorised by Edgar Dale's Cone of Learning.[24]

Despite the diverse field of adoption of VR, there is a lack of development in the area of postgraduate education where it has vast potential. At the Royal College of Surgeons in Ireland (RCSI) we have developed a virtual reality trauma simulator application for the Oculus Gear-VR. As this is the world's first fully-interactive medical decision-making simulation available on this virtual reality platform, there is a lack of data pertaining to its educational benefits.

The present study aimed to examine for evidence of validity within this proof-of-concept VR application, while acquiring meaningful feedback pertaining to the technology amongst the medical profession.

2. Methods

2.1. Virtual reality hardware

Samsung (Suwon, South Korea) Gear VR Head Mounted Displays (HMD, powered by Oculus, version SM-R322, Fig. 1) were connected to either Samsung Galaxy S6 or Galaxy S7-edge devices (Android 6.0.1). The HMD includes a touchpad-reticule interface allowing users to interact with instruments, objects and text within the Oculus platform (v1.22.3). Accelerometers (motion and infrared

Fig. 1. Samsung Gear VR (Courtesy of Samsung Electronics Ltd).

sensors) transcribe head movements of pitch (up-down), yaw (side to side) and roll (rotational) to orientations within the virtual space. This permits the headsets relatively small screens ($\geq$2160 $\times$ 1200 resolution) the ability to convey 360-degree digital environments.

2.2. Application

The application (v1.7.3) was developed on Windows-10 64-bit (Microsoft, Washington, United States), using Unity 3D (Unity Technologies, San Francisco, United States) Integrated Development Environment (v5.3.5) and Oculus Utilities (v1.3.2). 3DS-Max 2014 (Autodesk, California, United States) was utilised for 3D-object modelling. Scripted audio was integrated where appropriate.

A single trauma 'moulage' scenario was adopted from elements of the Advanced Trauma Life Support (American College of Surgeons, Chicago, Illinois) guidelines (9th Edition)[25] and developed within the Unity 3D engine. This scenario describes a patient arriving at the Emergency Department with blunt thoracic trauma (Fig. 2).

Several critical (patient death) and non-critical decisions and diagnoses (Table 1) were defined amongst authors prior to implementation. These included appropriate completion of the primary survey, responding to vital-monitor cues and recognizing life-threatening situations. These decision-making foundations were augmented with animations of patient examination which appropriately reflected pathology at a given time period. These animations included a cardiovascular examination with signs elicited and patient vital signs reflecting a traumatic pneumothorax. The moulage required the appropriate insertion of a chest drain and interpretation of trauma series x-rays, blood results and electrocardiogram. A fully didactic learning pathway within the virtual space was also developed but not trialled within this study.

2.3. Study design

This single-centre trial was conducted at an Advanced Trauma Life Support (ATLS) training course in Leinster, Ireland in 2016. All candidates (novice) and course-instructors (experts) were invited to participate over the three-day course. Exclusion criteria included: Previous use of the VR Training application, performing <75% of the simulation and individuals that both failed to complete the simulation and subsequent survey.

A standardized format of testing was employed: Participants were orientated to the Oculus Headset and watched a pre-loaded 'Introduction to Virtual Reality' application (Felix & Paul Studios, Montreal, Canada) to demonstrate the video capabilities of the technology for 360-degree content (Real Footage & Computer generated). Participants immediately proceeded to a single trial of the gratuitous VR application: RCSI medical training simulator

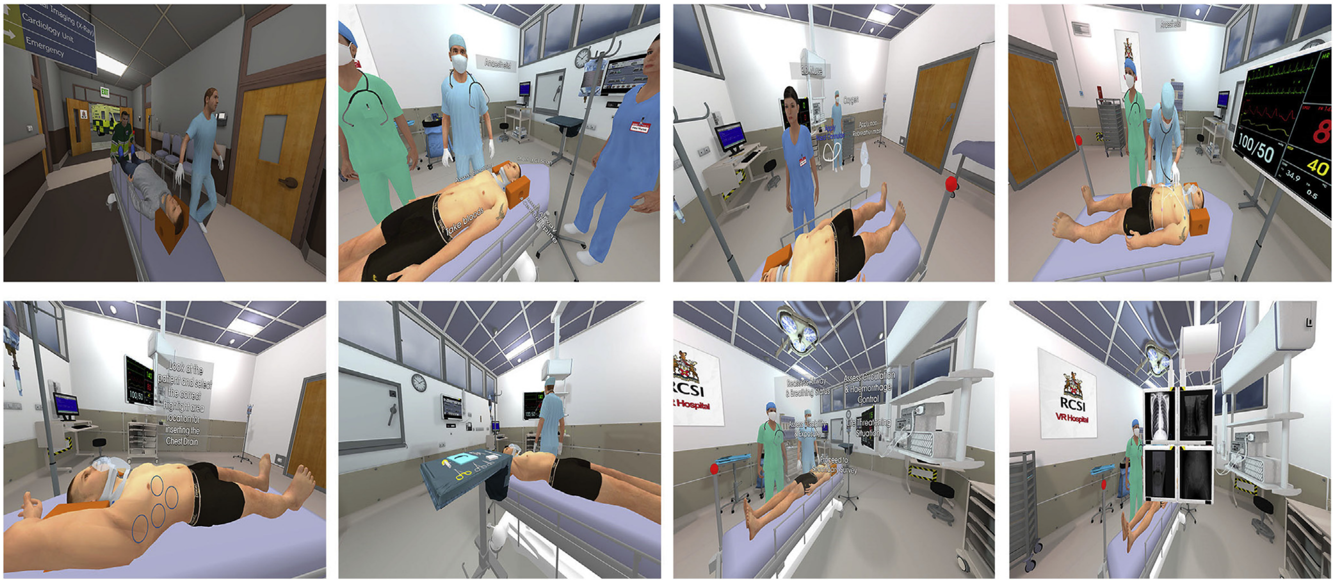

Fig. 2. Virtual reality simulator screen sampling.

(https://www.oculus.com/experiences/gear-vr/878262692296965). Performance scores were automatically recorded at simulation completion. These variables included: Number of Correct Decisions, Number of Incorrect Decisions, Number of Correct Diagnoses, Number of Incorrect Diagnoses, Number of Patient Deaths and Time Taken.

2.4. Survey design

Following the simulator trial, participants were invited to complete a web-based electronic survey without observation. This survey included demographics and 7-point Likert scale statements (Strongly Disagree [1] - Neutral [4] - Strongly Agree [7]). The statements related to aspects of the hardware, medical simulator and prospects of the application and technology.

2.5. Statistical analysis

Data analyses were performed using SPSS (IBM, New York, United States) Version 22.0, Windows-7 64-bit (Microsoft, Washington, United States). Simulator performances scores were correlated with expert/novice status using student's t-test and Fischer's exact-test where appropriate. Only participants that performed the simulation to completion were included in performance correlations. Proportions of decisions made incorrectly were analysed amongst participants. This was performed due to the variable nature of the simulator's decision-trees. Simulator performances amongst candidates were analysed with ATLS course MCQ assessments using Spearman Rank Correlation. Four re-verifying course candidates were excluded from MCQ correlation analysis due to previous exposure to the course content. Likert Scale survey feedback was weighted 1 to 7 with scores of 5 or more deemed positive, 3 or less deemed negative and median scores analysed for individual statements.

This study was approved by the regional medical ethics Committee (RCSI, Dublin, Ireland: REC 1202). All individuals consented to participation.

3. Results

Nineteen course candidates (86.4%) and 11 course instructors (84.6%) trialled the headset with survey completion acquired in 16 (84.2%) and 10 (90.9%) respectively. Simulator completion scores for the RCSI Training Simulator were achieved in 15 (78.9%) candidates and 7 (63.6%) instructors (Fig. 3). Failure to complete the simulator was principally due to course time-restrictions. One participant was excluded from the study due to both failures to complete the survey and the RCSI simulator to debrief.

Mean age of survey responders was 38.9 years and 80.8% were male (Table 2). The instructor group made significantly less fatal errors [virtual patient deaths] ($p = 0.049$) and lower proportions of incorrect decisions ($p = 0.045$) than the candidate group. There were no statistical differences in time taken or number of correct diagnoses (Table 3).

The simulator performances were analysed for correlations with candidates' course MCQ scores. Significant correlations were highly

Table 1
Critical and non-critical VR Decisions and Diagnoses.

Patient Death	Decisions	Diagnoses
Failure to adhere to primary-survey.	Adhering to trauma management protocol.	AP Pelvis x-ray.
	Correct application of adjuncts to primary survey.	Chest X-ray.
Failure to recognise Life threatening conditions.	Appropriate Patient Positioning	AP & Lateral Cervical Spine x-ray.
	Chest-drain directionality.	Open Mouth PEG x-ray.
	Local anaesthetic choice.	Arterial Blood Gas.
Incorrect site placement of chest drain.	Correctly responding to vitals monitor cues for IV fluids and warming.	Full Blood Count.
	Reassesses primary-survey after a major intervention.	Electrocardiogram (ECG).

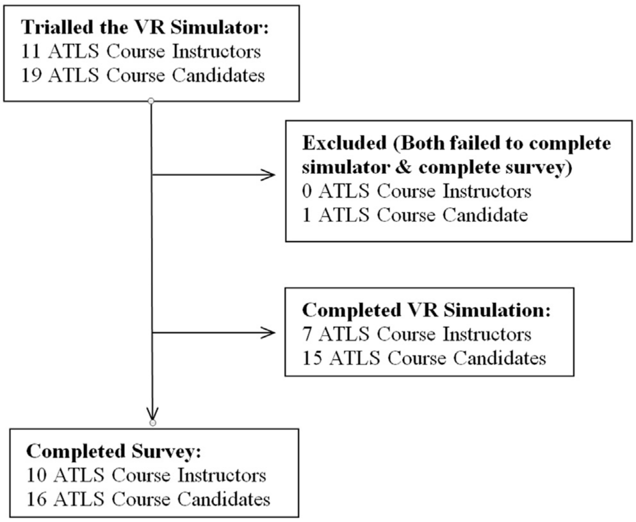

Fig. 3. Participant flow.

Table 3
Analysis of simulator variables.

	Instructors (n = 7)	Candidates (n = 15)	p-value[a]
No of Virtual-Patient Deaths			
- Mean	0.9 ± 0.7	2.9 ± 2.4	0.007
- ≤1 Deaths	6 (85.7%)	5 (33.3%)	
- 2 Deaths	1 (14.3%)	3 (20.0%)	0.049
- 3+ Deaths	0 (0.0%)	7 (46.7%)	
Decisions Made			
- No of Correct Decisions	21.9 ± 1.5	20.9 ± 2.0	0.435
- No of Incorrect Decisions	2.0 ± 1.5	4.6 ± 3.3	0.711
- Percentage decisions-made that were incorrect	8.3 ± 6.2	17.2 ± 10.1	0.045
Diagnoses Made			
- No of Correct Diagnoses	6.4 ± 0.8	6.1 ± 0.9	0.882
- No of Incorrect Diagnoses	1.1 ± 1.1	1.4 ± 1.2	1.000
- Time (seconds)	849.7 ± 11.3	857.7 ± 163.9	0.920

Continuous/Numeric data is presented as mean ± SD and categorical data is presented as n (%).
[a] Student's t-test for continuous data, Fisher's Exact Test (Freeman-Halton) for categorical data.

dependent on the exclusion of the top two MCQ performers. Once these two candidates were excluded, significant correlations were identified for proportion of incorrect decisions and MCQ result ($r = -0.672$ $p = 0.047$).

Feedback relating to the VR hardware and RCSI Training Simulator was predominantly positive (Fig. 4). The aggregated mean value for immersion and realism of the VR hardware was rated 5.09 and the realism and appearances in the Medical Training Simulator rated 5.04 (Appendix A). Overall, it was perceived to be an enjoyable method of learning (median rating 6.0), the learning platform of choice (median 5.0) and a cost-effective training tool (median 5.0).

The Medical Training Simulator was overall reported to be a useful teaching tool (mean 5.7 out of 7) and the majority (58%) of instructors and candidates felt there were not currently enough simulators available to simulate patient management (median 3.0) [Appendix B]. Feedback on future applications on the VR headset was generally positive with several areas of development deemed appropriate and scoring 6.0 out of 7.0 including: further medical decision-making simulators, anatomy visualisation and diagnostic patient imaging (Appendix C).

4. Discussion

This proof-of-concept application on the Virtual Reality Platform is the world's first medical decision-making simulator on Oculus virtual reality. The principle aim of this study related to confirmation of feasibility and proof-of-concept. In fact, evidence of several aspects of validity from this simulator has been demonstrated.

This simulator has confirmed its ability in distinguishing decision-making skills between differing levels of expertise. Higher scores in these skills were demonstrated in the instructor group, in keeping with the gulf in knowledge and experience between the two cohorts. However, diagnoses variances and time differentiation were not significant. This may result from the relatively low-complexity content within the application such as radiological imaging and laboratory results. The learning curve in familiarizing oneself with the technology and the generational 'digital-division' may also factor in the lack of time differentiation between the two groups. With increasing complexity scenarios these aspects may gain significance between individual levels of expertise.

Performance in the course MCQ did not correlate significantly with simulator performance in the overall candidate group. This was highly dependent on the two top performing MCQ candidates. One could hypothesise a number of reasons for this including that knowledge transferability to the VR simulator may be again impacted by the initial learning curve with the new technology. The MCQ also tests a far broader range of content and not predominantly decision-making skills.

Feedback from the electronic survey was predominantly positive. Both instructors and participants reported strongly positive visual immersion levels with the VR hardware of 5.5 and 6.0 respectively. The majority (88.5%) felt that being removed from external stimuli added to the immersive experience. Realism of the simulator content was reported favourably throughout all areas, with a minimum score of 5.0 (median). Both participant groups reported strongly positive enjoyment levels with the simulator and felt it was a cost-effective learning tool at current market value (median 5.0–5.5). Instructors were less enthusiastic in choosing this as a platform of choice for learning compared to candidates

Table 2
Course survey demographics.

	Instructors (n = 10)	Candidates (n = 16)	Total (n = 26)
Age[a]	49.1 ± 9.9	32.5 ± 5.3	38.9 ± 11.0
Gender			
- Male	9 (90)	12 (75)	21 (80.8)
- Female	1 (10)	4 (25)	5 (19.2)
Speciality			
- Orthopaedics & Trauma	4 (40)	4 (25)	8 (30.8)
- Emergency Medicine	4 (40)	7 (43.75)	11 (42.3)
- Anaesthesiology	1 (10)	–	1 (3.85)
- General Surgery	1 (10)	4 (25)	5 (19.2)
- Internship	–	1 (6.25)	1 (3.85)
Grade			
- Consultant	9 (90)	–	9 (34.6)
- Specialist Registrar	1 (10)	2 (12.5)	3 (11.5)
- Registrar	–	5 (31.25)	5 (19.2)
- Senior House Officer	–	8 (50)	8 (30.8)
- Intern	–	1 (6.25)	1 (3.85)
Experience with Virtual Reality HMD	1 (10)	2 (12.5)	3 (11.5)
Handedness			
- Right	10 (100)	14 (87.5)	24 (92.3)
- Left	–	2 (12.5)	2 (7.7)

[a] Mean ± SD, n (percent in parentheses).

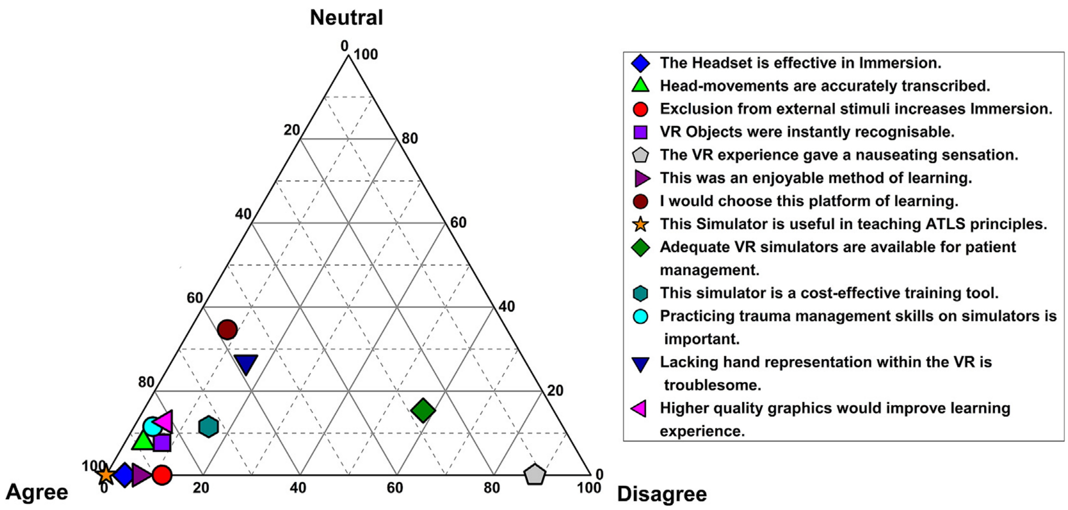

Fig. 4. Ternary plot of survey responses.

(median 5.0). We propose a number of factors for this discrepancy, which may be due to individual level of experience with technology and 'the digital-division'.[26] Most simulators are targeted as educational and assessment tools for trainees rather than experts; thereby appealing to the target audience should be a significant factor in simulator technologies. Reports indicate underuse of expensive, high fidelity simulators in the past due to lack of accessibility and enjoyment factors.[27] The Oculus Gear VR may overcome both of these deterrents, due to its portability, size and appealing immersion.

Several areas of improvement were indicated from the survey feedback. Responses to the 3D audio immersion and touchpad interface were reported less favourably (median 5.0) and may highlight areas for improvement in future iterations of the technology. This, in combination with integration of hand representation/interactivity within the virtual space may benefit the overall experience as 54% of responses suggest (median 5.0). The majority (84.6%) of responders reported that improved graphics would add to the learning experience and we believe enrichment of content is within the capabilities of the hardware. Future developers should focus upon increasing graphics quality and not solely functionality of medical applications.

The VR Simulator was perceived as a useful teaching and assessment tool in a number of fields. The majority of participants felt that practicing and maintaining trauma management skills on a VR simulator was important. However they reported that inadequate VR simulators were currently available for use (median response 3.0).

A sensation of nausea has been reported with previous VR experiences due to stimuli mismatches between the visual and vestibular senses.[14] This may be a subjective response or be specific to a given virtual reality experience. This medical application has largely stationary interactions and therefore levels of nausea were reported as low (median 2.0 of 7). Due to the placid nature of medical interactions, there are no reasons why future simulations would be associated with significant VR-related nausea.

4.1. Limitations

Several limitations should be appreciated with this study's results. As a small single-centre study, participants were predominantly male and largely representative from general surgery, orthopaedic surgery and emergency medicine disciplines. This may not fully represent the overall medical population with gender and speciality variances. This potential selection bias may positively skew survey results. Comparing groups with extremes of experience (instructors vs candidates) as with this study may inherently result in significant results. The instructor group was inherently older and predominantly male compared to the novice group. The study demonstrated incomplete data in achieving simulator completion and survey feedback. Although the majority of participants (66%) completed both, data failing to represent all participants may introduce non-response bias.

In an attempt to reduce acquiescence bias in feedback, bipolar scales with verbal explanations were presented to participants in the electronic survey after course completion and without observation. However one must appreciate that this, in combination with the novelty factor of the technology in 88.5% of survey responders, may positively impact feedback data.

Although this study has demonstrated evidence of a simulator's ability to differentiate decision-making skills and potentially a platform of learning into the future, we have not investigated the simulator as a learning tool or the transferability of associated learning to real practice.

4.2. Future applications

Future development prospects for VR in medicine are numerous and the challenge lies in anticipating the most beneficial fields of application. Virtual reality may not replace the learning and experience of managing a real-life patient but could provide another tool in the simulation arsenal for medical trainees, particularly in the home environment.

Whether future VR developments focus on immersive 360-degree video content such as operative/team dynamics or develop decision-making scenarios, ventures are bound to be fruitful. Survey feedback suggests (median response 6.0) virtual reality may be a suitable platform for visualising intricate 3D-structures such as anatomy learning or reconstructed patient imagery for diagnosis. Could VR become a viable tool for interpreting radiology or other medical imaging? The possibilities in the medical profession for both training and diagnostics are endless.

Virtual reality has massive potential and may be the pinnacle of learning platforms. Innovators must ensure that simulation modalities are evolving at a comparable pace as the medical technologies which we use on real patients. VR is another tool for the clinician to expand their knowledge and decision-making skills while bolstering already validated educational methodologies. Medical training is slowly moving away from the operating-room metaphor as "the surgeon's classroom and laboratory extraordinaire."[28]

Currently all eyes are on Virtual Reality. As aptly described over a decade ago (Gorman PJ[29]): "The future of medical education is no longer blood and guts, it is bits and bytes."[29]

5. Conclusion

This study has demonstrated the development and trialling of the world's first fully interactive medical training simulator on the Oculus VR platform. This proof of concept application has demonstrated evidence of multiple areas of validation. Feedback has been positive. It is the authors' aspirations that this study provides foundations for future medical developers on this platform.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.amjsurg.2017.02.011.

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