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Virtual Reality in Orthopaedic Pre-Operative Trauma Planning: A Face and Content Validity Study

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Abstract

Purpose: Virtual Reality (VR) has demonstrated value in surgical simulation and training, with emerging interest in its use for patient-specific pre-operative planning. Evidence evaluating VR systems for planning orthopaedic trauma surgery remains limited. There is little published on VR as a pre- operative planning tool in orthopaedic trauma surgery. After assembling a VR system utilising Medicalholodeck™ software to allow visualisation of stereoscopic 3D patient images with specific surgical implants in the same virtual space, we sought to collect early surgeon user data on the system's face and content validity.

Methods: Following software assembly, hardware acquisition, and iterative testing, a local user guide and pilot questionnaire were developed. The survey was based on established VR validation frameworks and pilot-tested with surgeons for clarity. Surgeons reviewed CT imaging on PACS and then repeated assessment in VR. Immediate qualitative and quantitative responses were collected. From this, face and content validity was evaluated and a Net Promoter Score (NPS) were calculated.

Results: Twenty-four responses were obtained across surgeon grades. VR significantly improved surgeons' understanding of fracture patterns (Wilcoxon signed-rank test: $Z = -3.93$, $p<0.001$, $r = 0.59$). All participants agreed that the VR representation matched PACS CT imaging, and 87% reported a change in operative plan. NPS was +71, with 75% promoters.

Conclusion: This early evaluation demonstrates strong face and content validity for a low-cost VR trauma planning tool. Further work will assess accuracy of implant templating and evaluate the system's role in patient explanation and consent.

Keywords: *Virtual Reality, Orthopaedic Trauma Surgery, Pre-operative Planning, Surgical Simulation*

Introduction

Virtual reality (VR) has been used increasingly for surgical training and simulation with positive results. There is evidence that VR use for patient specific pre-operative planning has the potential to enhance surgeon experience, though is in its relative infancy for planning orthopaedic trauma surgery. Most high fidelity systems currently available are high cost; this can limit widespread uptake in financially constrained public health systems. As there is little published evidence demonstrating face / content validity of these VR systems, we aimed to utilise existing 'off the shelf' solutions to allow virtual fracture visualisation with the ability to load implants into the same virtual space.

VR training simulators have seen increasing use in the education of future surgeons, with several advantages proposed over more conventional teaching methods. Use of VR for surgical planning has been shown to influence surgical strategy, enhancing both anatomical understanding and surgeon confidence [1]. Virtual environments also have the potential to provide surgeons with the opportunity to rehearse skills in 'realistic' simulated situations, without risk of harm to patients. Meta-analysis of 24 randomised controlled trials has demonstrated that VR improves both efficiency of trainee surgical practice and reduction of operative error rates [2]. Similarly, VR simulators have been shown to improve operative performance in trainees' use of robots, with improved technical skills transferrable to clinical tasks on cadaveric tissue [3]. In orthopaedic surgery, VR has demonstrated positive training impact, with potential to improve patient outcomes: systematic review of 29 papers described both accelerated development of orthopaedic technical skills and reductions in radiation exposure [4]. It has been noted that while VR cannot replicate hands-on operative experience, it does effectively supplement surgical training as an adjunct [5]. When designing new VR systems for usage in training, it is imperative to demonstrate initial face and content validity via pilot testing and feedback, though evidence is limited in the literature [1].

"Face Validity" has a critical role in development of new systems, describing the degree to which a test appears to subjectively measure what it purports to measure: in essence, how "realistic" it is. The common approach to demonstrate face validity is through expert evaluation, where a panel reviews the item in question to determine whether it seems representative of the construct being measured. Previous studies have demonstrated face validity of orthopaedic VR simulators (such as for hip arthroscopy), supported by user feedback on realism and ability to replicate real-world training scenarios [6].

In trauma, face validity of specific orthopaedic training simulators has been demonstrated in various pilot studies, such as in development of a virtual environment to rehearse proximal femoral nailing [7]. However, it has been highlighted that face validity alone is inadequate to determine overall validity, with a need to combine both quantitative and qualitative data in the assessment process [8]. Content validity is similarly determined through appraisal by specialists in the field to determine whether the simulation environment effectively represents real world clinical settings and reflects task relevant to practice [9]. However, there is wide methodological variability in demonstrating validity of orthopaedic VR trauma simulators, with no formal evaluation protocol across the literature [10].

While demonstration of face and content validity is important when undertaking pilot testing of new products, it is not in itself a comprehensive evaluation of user satisfaction. Usage of a "Net Promotor Score" (NPS) has been widely adopted across numerous service industries as a marker of user satisfaction by evaluating the likelihood that clients will recommend a product / service to others, in turn generating repeat usage [11]. Users are asked a single question to evaluate the NPS, expressed as the ratio of promoters to detractors: "How likely are you to recommend this to a friend or colleague?". Responses are given on a 0-10 scale, with "promoters" (who would recommend) giving a rating of 9-10, "passives" (who would not actively recommend) 7-8 and "detractors" (who discourage use) 0-6. An overall score is calculated by removing passive responses from analysis and subtracting the percentage of detractors from promotors. This generates a score between +100 (where everyone would promote) to -100 (where nobody would recommend). What is deemed a "good" NPS varies across sectors and industries, though in general a score of +50 is considered "good performance" and those of +70 "exceptional performance" [11]. Performance in surgery is often measured with other metrics, though NPS published from patients undergoing arthroplasty procedures show results comparable to large commercial organisations [12]. When used cautiously and with contextual limitations acknowledged, NPS can complement validity assessments by providing a pragmatic marker of clinician engagement for implementation planning.

While using patient-specific geometrical models in surgery has been described, there is little published in the literature on usage of VR as a pre-operative tool for surgical planning in trauma . To our knowledge, we are first in using a lower cost, high fidelity VR system running Medicalholodeck ™ software allowing visualisation of stereoscopic 3D patient images with specific orthopaedic surgical implants in the same virtual space [13]. Here, we present early user data on implementation of our local Lanarkshire Orthopaedic VR Environment. We sought to demonstrate face validity with questions designed to collect qualitative feedback from users regarding perceptions of system effectiveness and relevance, before generating a NPS to enhance our understanding of initial reception and surgeon engagement to inform further system development.

Material and Methods

System Setup

Our system was set up utilising MedicalHolodeck's MedicalImaging XR™ software (Zurich Switzerland), with object file models of implants provided by our trauma supplier (Stryker, Kalamazoo, USA) [13]. CT DICOM imaging was imported directly from PACS.

Participants

Data was collected from staff working within our Trauma unit, with over 22 full time orthopaedic trauma consultants, and 19 surgeons in training with a wide spectrum of specialty interest. A total of 24 system users utilised the VR system to visualise a patient CT image imported to the system through PACS patient imaging system. Users were free to select from both a variety of pre-uploaded appendicular skeleton scans, or upload their own cases in to the system for review. Participants were invited to review patient imaging files using standard "PACS" viewing format before utilising the system. While written instructions were provided, those less familiar with VR formats watched a live demonstration of use before independent system use. This was immediately followed by a questionnaire regarding user perception of the system, accessed via a scan "QR" code.

Survey Development

This consisted of 13 questions addressing the Face and Content Validity of the system utilising Likert scales. Items were generated by the study team, based on established VR / simulation validation frameworks [14)] before a final review of content relevance by two consultant orthopaedic surgeons. The questionnaire was pilot-tested with three surgeons (consultant and trainee) to assess clarity, comprehension, and response burden. Minor wording adjustments were made prior to deployment.

Ethics and IRB Exemption

This study involved staff evaluation of a non-clinical tool and did not include patient data beyond anonymised CT imaging used for teaching. Formal ethical approval was not required; however, confirmation of institutional review board exemption was obtained from NHS Lanarkshire R&D office.

Data Collection and Analysis

Responses were collected and analysed through Microsoft Forms. Likert scales assessed realism, understanding, usability, and planning impact. Pre- and post-VR understanding scores were compared using a Wilcoxon signed-rank test. NPS was calculated according to standard methodology.

Results

In total, a number of responses (N=24) were obtained from a variety of surgeon grades, including: Consultants (N=10), Specialty Trainees (N=8), Core Surgical Trainees (N=5) and Other (N=1). Participants described their previous experience using VR environments, with 33% (N=8) having never used VR, 38% (N=9) using less than 2 hours and 21% (N=5) using VR for between 2 and 10 hours, 2 participants had utilised VR for over 10 hours prior to this study. A variety of fracture types, from a variety of fracture regions were evaluated. This included Shoulder & Proximal Humerus (N=3), Wrist & Hand (N=4), Pelvis & Hip (N=5), Distal Femur & Knee (N=7) and Distal Tibia, Foot & Ankle (N=5).

Participants were asked to rate their subjective understanding of the fracture pattern visualised using CT strategies alone through Carestream PACS on a normal PC before their use of VR using Likert scales 1-5, describing their understanding as "Poor" (1), "Fair" (2), "Good" (3), "Very Good (4), or "Excellent (5), 8% (N=2) rated their understanding as "Poor", 21% (N=5) as "Fair", 46% (N=11) as "Good", 17% (N=4) as "Very Good" and 8% (N=2) "Excellent". Participants were then asked to rate their understanding of the same fracture after the use of the VR system. Participants then rated their understanding as "Good" in 17% (N=4), "Very Good" in 33% (N=8) and "Excellent" in 50% (N=12). No participants reported "Poor" or "Fair" understanding after the use of VR.

Surgeons' test results were compared before and after the use of VR. On average, participants reported better understanding after the use of VR. Data was analysed and was found to be non-parametric, therefore a Wilcoxon signed-rank test was used which demonstrated a significant difference between the pre and post scores ($Z = -3.93$, $p<0.001$, $r = 0.59$) indicating a statistically significant effect. Comparison histograms are seen in Figure 1.

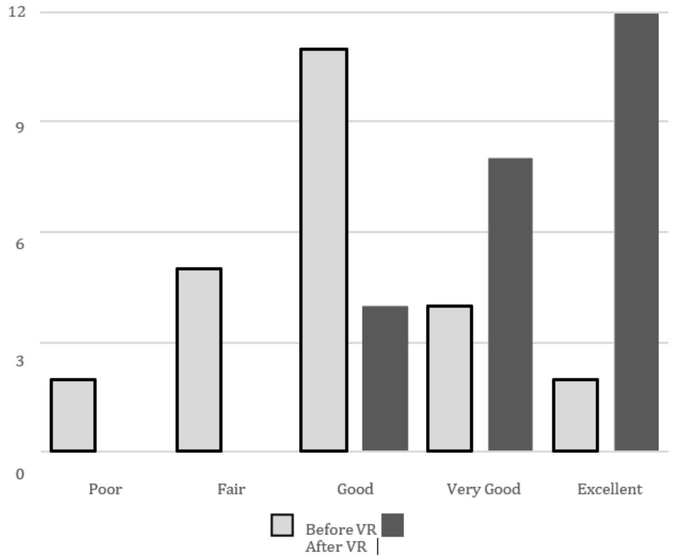

Figure 1. *Surgeon perceived understanding before and after using VR system (number on Y axis).*

Participants were asked whether the VR simulation of the CT scan matched the PACS CT closely on likert scales of 1 - 5, ranging strong disagreement to strong agreement. All participants either “Strongly Agreed” (58%, N = 14) or “Agreed” (42%, N=10).

Participants were asked whether VR was helpful in planning fixation of the fracture compared to CT visualisation alone on likert scales of 1 - 5, ranging “Very Unhelpful” to “Very Helpful”. The majority (67%, N = 16) reported VR as “Very Helpful”, with 21% (N=5) as “Helpful” and 13% (N=3) as “Neither Helpful nor Unhelpful”.

Participants were asked if the use of VR had changed how they planned to fix the fracture compared to CT alone. Respondents reported a “Substantial” change to their plan in 46% (N=11) and a “Small” change to their plan in 42% (N=10) cases. No change was reported in 13% (N=3) of cases.

Participants were asked if their use of VR increased their confidence in the specific implant choices required for their planned fixation strategy. Respondents reported a “Substantial” confidence increase in 58% (N=14) and a “Small” confidence increase 38% (N=9) cases. No change was reported in 4% (N=1) case.

Participants were asked how likely they were to use VR for the next complex fracture they were involved with compared to CT visualisation alone, using Likert scales 1-5 ranging “Very Unlikely” to “Very Likely”. Respondents were “Very Likely” to use the system again in 46% of cases, “Likely” in 29% (N=7) and “Neither Likely nor Unlikely” in 13% (N=3).

12% (N=3) of partipants said that they were “Unlikely” or “Very Unlikely” or to use the system again.

To generate a Net Promotor Score (NPS), participants were asked how likely they would be to recommend this VR set up to a colleague on a likert scale 1 - 10, ranging “Not at all likely” to “Extremely Likely” . In total, 75% (N=18) ranked as “Promotors”, 21% (N=5) as “Passives” and 4% (N=1) as “Detractors”. This generated an overall NPS of +71 (Promotors - Detractors).

Discussion

This study demonstrates strong early face and content validity for a low-cost virtual reality system designed for orthopaedic trauma pre-operative planning. Surgeons reported significantly improved understanding of fracture morphology and a high degree of realism when comparing VR rendering with PACS imaging. This aligns with published literature showing that VR enhances anatomical interpretation, decision-making confidence and pre-operative preparedness across multiple surgical specialties.

Our findings complement earlier orthopaedic VR studies demonstrating validity in hip arthroscopy simulation, trauma nailing rehearsal and robotic surgery skills training [6–10].

These studies emphasise the importance of user-perceived realism and relevance—core elements of face and content validity—before wider implementation. The significant change in operative planning reported here supports emerging evidence that VR can influence surgical strategy by improving depth perception and spatial orientation relative to 2D imaging.

There is significant potential that the trauma user base of this (and other) Virtual systems will increase rapidly in coming years. Although originally developed for commercial settings, NPS is increasingly applied within healthcare, with uses including: assessment of digital health platforms, evaluation of medical education interventions and user acceptance of new clinical technologies [11–12]. Given its simplicity and interpretability, NPS provides a useful adjunct to validity testing by capturing early clinician engagement, which is essential for implementation success. However, NPS has recognised limitations, with suggestion that use in healthcare settings is not supported by research [15]: it is a single-item measure, influenced by context, and not a substitute for multidimensional evaluation.

Previous analysis of 3758 trauma patients from the Netherlands has demonstrated an operative error rate of 1.8%, with a large number of these related to incorrect implant positioning and length [16]. We believe these early positive results of this novel technology's perceived usefulness and validity demonstrates that this system could provide benefit to staff and patients alike in future by aiding reduction of surgical error in trauma surgery. However, further studies to validate scaling and accuracy of implant sizes will need to be undertaken in this system before adoption for accurate 'templating' type use in trauma. We plan to compare pre-operative implant selection in VR to definitive implantation sizes in the operating theatre to demonstrate system predictive accuracy.

Additionally, we have also started utilising the system to better visualise and understand elective 'deformity' cases. While pre-operative templating has been shown to improve surgical accuracy with component positioning in robotic assisted arthroplasty [17], further work is required to demonstrate validity of the use of our VR system in the elective setting.

Further applications may be possible in surgical training, with VR 'rehersal' having been shown to improve procedural accuracy and completion rates when undertaking tibial nail procedure on sawbones [18].

Analysis of our results has demonstrated a highly favourable initial reaction to the system amongst trauma surgeons, suggesting adequate realism for use in pre-operative planning for trauma. There is potential to aid implant selection and execution of surgical plan. This is in keeping with previous studies highlighting surgeon preferences for utilisation of both standard 'desktop' viewers wtih a VR solution to visualise virtual models [19] and use of 3D VR environments to aid surgical planning [20].

Limitations

Several limitations to our work should be acknowledged. This paper represents a single- centre study with a modest sample size, which may limit generalisability. A selection bias in responses may be present, as participation was voluntary. Although pilot-tested, our questionnaire was not a formally validated instrument; further psychometric evaluation is needed. Results of our study assessed perceived effectiveness rather than objective performance metrics (e.g., operative time, accuracy of reduction). Additionally, our findings reflect short-term exposure only; usability and integration over time were not evaluated. While NPS provides insight into user sentiment, it is not a comprehensive measure of educational quality.

Conclusions

This study presents early evidence supporting the face and content validity of a low-cost VR system developed for orthopaedic trauma pre-operative planning. Surgeons reported improved understanding of complex fractures, high realism, and positive user experience. Future research will focus on validating implant-templating accuracy, assessing impact on surgical performance, and exploring use in patient education and consent.

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Competing Interests

The authors have no relevant financial or non-financial interest to disclose. The authors sought permission for the use of Figures in text from the relevant companies (Medical HolodeckTM and StykerTM).

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Dominic Waugh. The first draft of the manuscript was written by Dominic Waugh and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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