






Augmented reality for medical education in the primary survey of burns: an exploratory study

Milly S. van de Warenburg^{a,*} , Carolien Kamphuis^{b,c} , Stefan Hummelink^a ,
Dietmar J.O. Ulrich^a , Mariëlle L.A.W. Vehmeijer-Heeman^a 

^a Department of Plastic, Reconstructive and Hand Surgery, Radboud University Medical Centre Radboudumc, The Netherlands

^b Radboudumc Health Academy, Radboud University Medical Center Radboudumc, The Netherlands

^c BlinCK Educational Innovation, The Netherlands

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ABSTRACT

Introduction: Augmented reality (AR) technology is rapidly evolving and is finding an increasing application in education, including medical training. This feasibility study aimed to explore the usability and didactic potential of AR with the HoloLens2™ for medical students, teaching the primary survey of burn wounds.

Methods: This feasibility study was conducted using a prospective observational cohort design. Test groups consisted of participants with limited ($n = 18$), moderate ($n = 10$), or high ($n = 5$) experience in burn care, and filled in a questionnaire after training with the HoloLens2™.

Results: Outcomes of the questionnaires show AR to be a promising technology for educating medical students in the primary survey of burn wounds.

Discussion: However promising, there is further need for development in usability and image quality. The ability to simulate realistic scenarios in a safe and scalable environment could pave the way for a new era for medical education, where AR becomes a valuable supplement or even replacement for traditional learning methods.

Introduction

Extended reality (AR) is an innovative technique to encounter real-world based experiences that are either enhanced by digital elements or data (Augmented Reality, AR), or immerses users in a fully digital environment (Virtual Reality, VR) [1]. These technologies are rapidly evolving and finding increasing applications in healthcare, such as in patient education, surgical planning of complex procedures like free flap surgery, and medical training [2–7]. Due to the possibility to blend physical and virtual environments, AR-based programs are broadening learning experiences and provide means of understanding complex medical concepts [1,8]. One of the key advantages of immersive technology is its ability to offer interactive experiences that bridge the gap between theoretical knowledge and practical applications [5]. Specifically, AR could offer a transformative solution by overlaying virtual patients onto the real world, as well as information on the primary survey burn wounds [9,10]. The primary survey of burn injuries, a structured assessment of burn depth (colour, aspect, blisters, suppleness,

capillary refill, sensibility), extent (Total Body Surface Area, TBSA), and severity, presents unique educational challenges due to the limited availability of realistic training scenarios and hands-on training. Unlike many other medical conditions, burns exhibit highly variable wound patterns that evolve over time, making standardized training difficult [11,12]. Traditional methods, such as clinical photographs or actors, are often constrained by logistical or financial barriers or fail to replicate the dynamic nature of these injuries.

AR technology provides simulated clinical scenarios in controlled environments, granting students access to safe learning situations that are otherwise difficult to experience first-hand [5,8,10]. Using AR could enable a flexible and easily deployable solution to create learning experiences that are independent of time and place, in contrast to traditional methods involving actors, which are relatively costly, and require extensive planning. This feasibility study was designed to explore the potential of AR as a tool for educating medical students about the primary survey of burn wounds using the Microsoft HoloLens2™ (Microsoft, USA). By using virtual patient projections, we

* Corresponding author at: Department of Plastic, Reconstructive, and Hand Surgery, Radboud University Medical Centre, Geert Grooteplein Zuid 10, 6525, GA, Nijmegen, The Netherlands.

E-mail address: milly.vandewarenburg@radboudumc.nl (M.S. Warenburg).

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sought to assess whether this innovative approach could enhance learning outcomes and provide a more effective alternative to traditional educational methods. Given the complexity and variability of burn injuries, AR-based training could allow learners to practice identifying different burn depths, understanding wound progression, and making clinical decisions in a risk-free environment.

Materials & methods

The study protocol design and reporting adhered to the STROBE guidelines for the reporting of observational cohort studies along with the extension for simulation-based research [13]. This feasibility study was conducted using a prospective observational cohort design. It was performed at the Radboud University Medical Centre, from 2022–2024 to evaluate the usability of AR with the HoloLens2™ for medical education.

Test groups received a traditional lecture on burn wounds and their primary survey, as is standard in the curriculum of medical students [14, 15] (Fig. 1). Additionally, participants in this study received an introduction into the use of the HoloLens2™.

Intervention

The HoloLens2™ is an augmented reality headset developed and manufactured by Microsoft (Redmond, USA), capable of visualizing 3D models into head-mounted display. Our dataset comprised of 3D images of burn wound patients treated in our department. The cases were uploaded into the HoloLens2™ after obtaining patient consent, and were accompanied by details regarding the trauma mechanism. Participants observed these 3D virtual patient models and case information projected in the classroom. Multiple-choice questions related to the primary survey of the shown burn wounds were presented (Fig. 2).

Participants

Test groups with various experience levels were subjected to training of the primary survey of a burn patient. The test groups either consisted of 1) medical students or nurses with little to no experience in burn care, 2) residents or nurse specialist with moderate experience in burn care, or 3) experienced plastic surgeons. The rationale for including these groups was to gather valuable input from entry-level learners for user-friendliness and appropriate challenge, while also incorporating clinicians with moderate to high experience to ensure clinically accurate and representative examples. Participation was voluntary. After receiving the training, the participants individually wore the HoloLens2™ and went through the patient cases.

Two questionnaires were developed to evaluate either the didactic



Fig. 2. Medical students and a medical specialist using the HoloLens2™ as a tool for education on the primary survey of burn wounds with a visualization of the used images.

potential of the HoloLens2™ during medical training, or to evaluate its quality and usability. As no validated instrument available in the participant's native language at the time of conducting this study, these questionnaires were assembled with the help of educational specialists and a statistician. Items were adapted from existing instruments, resulting in a short and long questionnaire (see Table 1, Appendix 1). All items were rated using a four-point Likert scale (strongly disagree, disagree, agree, strongly agree). All participants were asked to fill in the short questionnaire. Afterwards, they were asked to fill out the long questionnaire as well.

Objectification of outcomes

All medical students took a written exam at the end of the block, similarly to their predecessors who received burn education by a traditional lecture and photographs, only without the use of AR. Test results ranged from 1–10, with 1 being the lowest grade, and 10 the highest.

Outcomes and statistical analysis

Participants' characteristics of each test group were analysed using descriptive statistics. Discrete variables were displayed as absolute frequencies and percentages. Continuous variables were displayed as mean and standard deviation. Moreover, mean test results were calculated for all students who took the course between 2022–2024, and are displayed for groups who did not receive AR education, and the students who did.

Table 1
Questionnaire on the didactic potential of AR.

| Questions | |
|-----------|--|
| 1 | The HoloLens is a better alternative to training the primary survey of burns with photos only for medical students |
| 2 | The HoloLens is a better alternative to training the primary survey of burns with photos only for residents |
| 3 | The HoloLens is a better alternative to training the primary survey of burns with photos only for medical specialists |
| 4 | By training with the HoloLens, you can learn all aspects of evaluating a burn wound (such as estimating the TBSA) as you would in physical examination of a real patient |
| 5 | The HoloLens has the potential to become a valid training tool for the primary survey of burns in the future, but now it is not |
| 6 | The HoloLens is an equivalent tool for training the primary survey of burns when compared to training with actors |
| 7 | The training with the HoloLens is an addition to learning this education from a book |

TBSA = Total Body Surface Area.



Fig. 1. Classical introduction on burn wounds and the use of the HoloLens2™.

Mean results between the groups were compared using an independent Student t-test using IBM SPSS Statistics (IBM Corporations, version 29) [16].

Results

In total, 48 medical students or nurses participated in the AR education. Of these participants, 18 filled in the short questionnaire. Additionally, 10 residents or nurse specialists, and 5 plastic surgeons utilized the 3D application on burn wounds and filled in the short questionnaire (Table 2, 33 participants in total). Thereafter, 10 participants (6 medical students or nurses, 3 residents or nurse specialists, and 1 plastic surgeon) agreed to fill in the long questionnaire. Most participants had little to none experience using AR.

Questionnaire on the didactic potential of AR

Most medical students, residents, and plastic surgeons agreed that AR is a better alternative to training the primary survey of burn wounds compared to using photographs only, with agreement rates ranging from 70 (7/10) to 94 % (17/18, see Fig. 3 and Appendix 2). Additionally, most plastic surgeons (80 %, 4/5) believed that using the HoloLens2™ provided additional value beyond textbook-based training.

Students and residents generally considered the 3D technology a suitable tool for learning all aspects of burn wound assessment, reflecting the experience of clinical practice (with 94 % (17/18) and 80 % (8/10) agreement, respectively). Plastic surgeons had mixed views on this, but still 60 % (3/5) agreed. Almost all participants –whether students, residents, or plastic surgeons –acknowledged that the AR has the potential to become a valuable training device for burn wound assessment, but has not yet fully reached this point (83 (15/18) to 100 % (10/10 and 6/6) agreement). Opinions diverged regarding whether AR is equivalent to training with actors, with only 28 (5/18) to 60 % (5/10 and 3/5) agreement. Additional details are provided in Appendix 2.

Questionnaire on the quality and usability of AR

Most medical students found AR to be realistic, motivating, and educational (83 %). All students agreed that AR provides unique opportunities to practice scenarios that would otherwise be inaccessible, and experienced a safe learning environment using this headset. Furthermore, students expressed a wish for more AR-based education. The majority of students felt that AR helped them achieve their learning goals and made them better prepared for practice (4 out of 5 (83 %) agreed, while 1 (17 %) was neutral). Among residents, opinions were split, with 67 % (2 out of 3) agreeing with the students’ sentiments and 33 % (1 out of 3) disagreeing with previous statements. Almost all

Table 2

Demographic information of the participants completing the short questionnaire.

| | Limited experience (students, nurses) | Moderate experience (residents, nurse specialist) | High experience (plastic surgeons) |
|----------------------------------|---------------------------------------|---|------------------------------------|
| Total short questionnaire (n) | 18 | 10 | 5 |
| Mean age (SD, range) (years) | 21.6 (SD 1.6, 20–26) | 31.1 (SD 7.6, 25–50) | 43.4 (SD 5.5, 39–52) |
| Experience in burn care (n (%)): | | | |
| <50 burn wounds | 18 (100) | 7 (70) | 0 (0) |
| ≥50 burn wounds | 0 (0) | 3 (30) | 5 (100) |
| Experience using AR (n (%)): | | | |
| None | 14 (78) | 5 (50) | 3 (60) |
| Little | 3 (17) | 5 (50) | 2 (40) |
| Some | 1 (6) | 0 (0) | 0 (0) |
| Lots | 0 (0) | 0 (0) | 0 (0) |

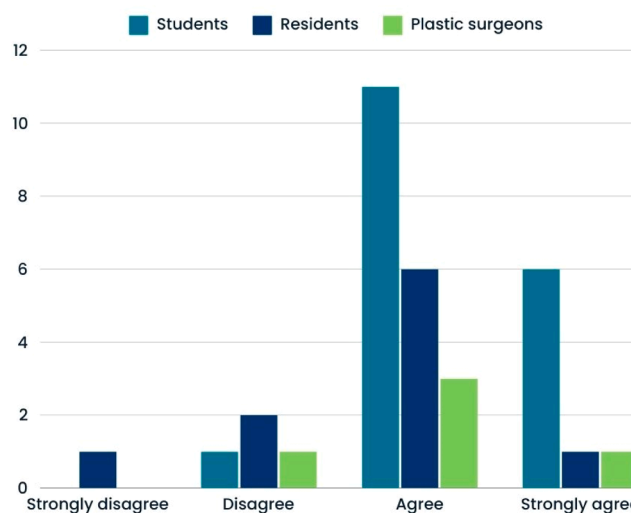


Fig. 3. Question 1: AR is a better alternative to training the primary survey of burns with photos only for medical students, answered by students, residents, and plastic surgeons.

participants (90 %, 9/10) found that they were able to assess the TBSA accurately, identify specific burn patterns (90 %, 9/10, e.g. shoes and socks, donut configuration, and zebra stripes), and to evaluate the presence of circular wounds and demarcation lines (90 %, 9/10 and 80 %, 8/10, respectively). Most of the students and residents found that AR provided a realistic representation of burn wounds (89 %, 8 out of 9), while the plastic surgeon disagreed.

There were mixed views on the clarity of uniform wound depth (70 %, 7/10, agreement), how easy it was to distinguish between dull and shiny wound beds (60 %, 6/10, found this easy), and to spot (ruptured) blisters (50 %, 5/10). Students were consistently more positive than residents and plastic surgeons on these matters.

In regard to the usability and comfort of the HoloLens2™, most participants found it to be user-friendly (80 %, 8/10) and none of them was nauseated while using the device.

Positive feedback highlighted that AR was a fun and interactive way to train for the primary survey of burn wounds. Some users appreciated that it provided a calm yet realistic experience, kept them engaged throughout the training, and facilitated effective learning where teaching material stuck. It was seen as a valuable tool for group training, distinct from other educational methods. Moreover, it was seen as future-friendly. Areas for improvement included the device’s user-friendliness, the need for an increased interactivity, and better resolution in terms of colour accuracy and image clarity.

Objectification of outcomes

Students who received traditional education achieved a mean test score of 5.0/10 (n = 29). In contrast, students who received AR-based education in addition to the traditional lecture obtained a significantly higher mean score of 7.7/10 (SD 1.9, n = 48). An independent two-sample t-test demonstrated a statistically significant difference between the groups (p < 0.001).

Discussion

This study aimed to explore the potential of AR, specifically using the HoloLens2™, as an educational tool for teaching medical students the primary survey of burn wounds. The potential was evaluated by medical students, residents, and plastic surgeons, with varying levels of experience with burn wound care and AR technology. Our findings suggest that the use of AR in this context was generally well-received,

particularly amongst medical students. This group emphasized the interactive nature of AR providing a new and engaging learning experience, and allowing them to practice in a safe environment. This is in contrast with traditional methods, such as learning from textbooks or photographs, and offers an alternative or complementary educational resource. Furthermore, the AR simulations presented scenarios that might otherwise be inaccessible. Our results are in line with past literature, presenting augmented reality as a promising tool in healthcare, for patient education, surgical planning of complex procedures, and medical training [10,17–19]. Since burn wound education presents unique challenges, with real-life experiences being limited and unpredictable, this ER tool could enable students to practice visual and tactile assessment techniques, improving their ability to recognize different burn depths and sizes, and prepare them for real-world scenarios. Learning objectives related to burn wound assessment were met through this approach, according to medical students themselves, and resulted in significantly higher test scores.

However, the reactions from residents and specialists regarding the added value of AR varied. Many acknowledged the need for further refinement in terms of usability and image quality before AR could be considered a “valid tool” for training the primary survey of burn wounds. One resident in particular expressed strong disagreement with several aspects in the questionnaire, emphasizing difficulties in use and low resolution of images, which contributed to a negative view of its current educational value. Feedback from more experienced participants further indicated that while technology has potential, it requires significant development to be a practical replacement for live actors in educational settings.

Several limitations were identified in this study. First, this study was an exploratory study, leading to a relatively small sample size, which affects the reliability and generalizability of the results. Notably, there was a significant disparity in the distribution of participants, with medical students outnumbering professionals. This imbalance may have skewed the overall perception of AR’s effectiveness, as the majority of feedback came from less experienced clinicians. However, as this tool is primarily meant to educate students in this study, and they are the target audience, the higher representation may not necessarily be a drawback. Future research should incorporate validated evaluation instruments (e.g., System Usability Scale), objective measures of learning outcomes (e.g. pre- and post-test assessing skills), and evaluate the use of AR in broader settings, including a broader and more balanced study sample, in a randomized controlled trial or longitudinal study. This would enhance generalizability, power, and make results comparable to other studies.

Another key limitation is the use of a cost and accessibility of AR technology. Devices such as the HoloLens2™ are expensive and may not be readily available to institutions with limited resources. The financial barrier associated with acquiring these devices could hinder widespread adoption. Despite these limitations, AR remains a scalable educational tool that could be easily adapted and deployed across a wide range of learning environments, medical specialties, and user skill levels without requiring significant changes to the core technology. This allows for consistent use in educational programs for medical students and residents. Additionally, a database with patient data can be built so that all future users can have the same learning experience. As a result, this exploratory study shows that AR could potentially transform medical education by providing a customizable, reusable, and scalable approach to teaching. This leads to a more uniform exposure and education. Furthermore, AR offers the possibility to practice scenarios with children, in contrast to the training with actors, who are exclusively adults.

Conclusion

While this exploratory study shows that AR might be a promising tool for educating medical students in the primary survey of burn wounds, there is a need for further development in usability and image

quality before it can be considered for broader implementation. Further development and more extensive evaluation are needed to determine its effectiveness in diverse educational settings. Nonetheless, the ability to simulate realistic scenarios in a safe and scalable environment, might pave the way for a new era of medical education, where AR could become a valuable supplement or even replacement for traditional learning methods.

Ethics statement

This study is not subjected to the Medical Research Involving Human Subjects Act (WMO) as participants are participating voluntarily and there is no infringement on physical or psychological integrity. Therefore, no review has been conducted by a medical ethics committee.

CRediT authorship contribution statement

Milly S. van de Warenburg: Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Carolien Kamphuis:** Writing – review & editing, Supervision, Conceptualization. **Stefan Hummelink:** Writing – review & editing, Supervision, Methodology. **Dietmar J.O. Ulrich:** Writing – review & editing, Supervision, Conceptualization. **Mariëlle L.A.W. Vehmeijer-Heeman:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology.

Declaration of competing interest

None.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.injury.2025.112747](https://doi.org/10.1016/j.injury.2025.112747).

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