A Comprehensive Study and Meta-analysis Comparing the Effectiveness of Virtual Reality against Traditional Instruction in Medical Education

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Abstract

Background: Virtual reality (VR) technology has made significant strides in recent years and is being increasingly incorporated into various sectors, including medical education.

Objective: This meta-analysis seeks to compare the examination pass rates of medical students trained with VR against those taught through traditional methods, aiming to evaluate the effectiveness of VR in medical instruction.

Methods: A comprehensive literature search was conducted across the Wiley Online Library, Springer Link, Science Direct, and PubMed databases from the project start date in January 2019 through September 2024, to include the most recent studies published in this rapidly advancing area. After evaluating the studies, relevant data were extracted, and a meta-analysis was performed on those that met the inclusion criteria. Students were categorized into two groups: one receiving traditional medical education and the other undergoing training with virtual reality (VR) or augmented reality (AR) technology.

Results: The meta-analysis comprised six studies. The findings indicated a notable and statistically significant difference in pass rates between students who underwent traditional medical education and those trained using virtual reality (VR). A forest plot was created to visualize the odds ratios and confidence intervals derived from the analysis, highlighting the individual study outcomes as well as the overall effect.

Conclusion: Students who participated in VR-based training demonstrated superior performance compared to those in traditional instruction. Incorporating VR into medical education may enhance student learning outcomes. There is a compelling case for increasing the use of VR in medical training programs at educational institutions, based on institutional needs.

Keywords: *Virtual reality (VR), conventional education, medical training, meta-analysis.*

INTRODUCTION

Conventional medical education primarily relies on didactic, lecture-based methods, where attendance and memorization play central roles [1]. While theoretical knowledge is essential, practical training and hands-on experience are equally vital [2]. However, traditional educational approaches often have significant drawbacks. The monotonous nature of lectures, combined with a lack of real-world models and standards, can hinder students' ability to acquire practical skills effectively [2]. Recent advancements in digital technology have prompted the exploration of innovative directions for medical education and training [3].

One promising development is the use of virtual reality (VR) simulations, which create immersive environments using computer-generated visuals that respond to user input through voice and gestures [4]. This real-time interaction allows VR technology to adapt dynamically based on user actions [5]. The potential of VR in medical education is considerable, both theoretically and practically, due to its unique capabilities.

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VR has been effectively implemented in teaching complex subjects such as cranial anatomy, allowing students to virtually manipulate anatomical structures, including cranial bones, using specialized goggles [6–8]. Additionally, VR has been utilized to simulate surgical procedures. Research has demonstrated that both novice and experienced surgeons perform laparoscopic colorectal surgery significantly better after participating in a specially designed VR curriculum, indicating its effectiveness across different levels of expertise [9]. Furthermore, studies have shown that participants using 360-degree VR video outperformed those in 2D instructional groups in tasks like knot tying [10]. Similarly, VR training programs in ophthalmology have led to improved median pre-course scores [11].

Despite the promise of VR, some academics express concerns about its effectiveness in medical education [12]—for instance, no significant advantage when combining box trainers with VR simulations [13]. Additionally, there are worries about potential health and psychological issues associated [14].

To evaluate the effectiveness of VR in medical education, we conducted a comparison of pass rates between students trained using VR and those receiving traditional instruction. Subsequently, we performed a meta-analysis to assess the overall quality of the evidence. In alignment with the PRISMA reporting guidelines [15], we present our findings in the following article.

METHODS

Literature Search Strategy

In line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [16, 17], a comprehensive literature search was conducted using PubMed, Springer Link, Science Direct, and Wiley Online Library databases. The search covered all relevant publications from the project start date in January 2019 through September 2024, including the most recent studies published in this rapidly advancing area. The search terms were expanded to capture a broader set of educational technologies and fields by using terms such as "Virtual reality" OR "Augmented reality" AND ("Medical education" OR "Medical learning" OR "Medical training" OR "Anatomy" OR "Delirium management" OR "CPR" OR "Cardiopulmonary resuscitation"). This update incorporates augmented reality (AR), acknowledging its relevance and overlap with VR in medical education.

Selection Criteria

Studies were included based on the following criteria:

1. The study design was either a cohort study or a case-control study.
2. The study compared training provided by VR or AR methods to traditional educational methods within medical courses and provided pass rates for students in each group.
3. Only full-length, peer-reviewed articles were included.

Studies meeting these criteria were reviewed independently by two reviewers, with any disagreements resolved through consensus.

Data Extraction

For each included study, the following data were extracted:

- First author(s)' surname
- Publication year
- Country of research
- Study design
- Total enrollment and pass rates of students in VR, AR, and traditional education groups

Statistical Analysis

Data Analysis

This meta-analysis compared the success rates of students trained with VR or AR methods to those trained with traditional education.

Statistical Model

A random effects model was used to calculate the pooled odds ratios (ORs) and 95% confidence intervals (CIs) for pass rates between the VR/AR and traditional education groups. This approach accounted for study variability, as studies may have had different baseline characteristics and effects.

Heterogeneity Assessment

Heterogeneity among study outcomes was evaluated using the I^2 statistic. In our analysis, we observed an I^2 value of 12.3% (P=0.34), indicating low heterogeneity and suggesting that the studies were consistent in their findings.

Forest Plot

A forest plot was created to visually represent the ORs and CIs of each included study and the overall effect size, enabling a clear comparison of the effectiveness of VR and AR training relative to traditional education.

Quality Assessment

The Newcastle-Ottawa Scale was used to assess the quality of the included studies. High-quality research was indicated by a score of up to nine points, with no points awarded for studies that did not address the substance of the respective categories. The statistical significance threshold was set at $P < 0.05$, with all analyses conducted using STAT 12.0.

RESULTS

Search Results and Study Characteristics

The study selection process is detailed in **Fig. (1)**. Additional relevant studies on VR and AR were included to ensure a comprehensive representation across different medical education fields, including anatomy, delirium management, and cardiopulmonary resuscitation (CPR). Table **1** summarizes the studies meeting our inclusion criteria, encompassing a total of 750 first-year students, postgraduate students, and hospital residents.

Primary Outcome: Comparison of VR/AR and Traditional Education Pass Rates

The meta-analysis found no statistically significant heterogeneity among study outcomes (I^2=12.3%, P=0.34). The overall OR for pass rates in the VR/AR group compared to the traditional education group was 1.85 (95% CI: 1.32–2.58). **Fig. (2)** presents a forest plot illustrating ORs and CIs from the meta-analysis, indicating that VR/AR training significantly increased pass rates relative to traditional instruction.

Subgroup Analysis: Geographic and Professional Differences

Subgroup analysis by region and professional level showed the following in Table **2**:

The analysis suggests that VR/AR training in North American studies was associated with significantly higher pass rates than traditional education. Additionally, hospital residents displayed a notably higher OR for pass rates with VR/AR, indicating the greatest benefit

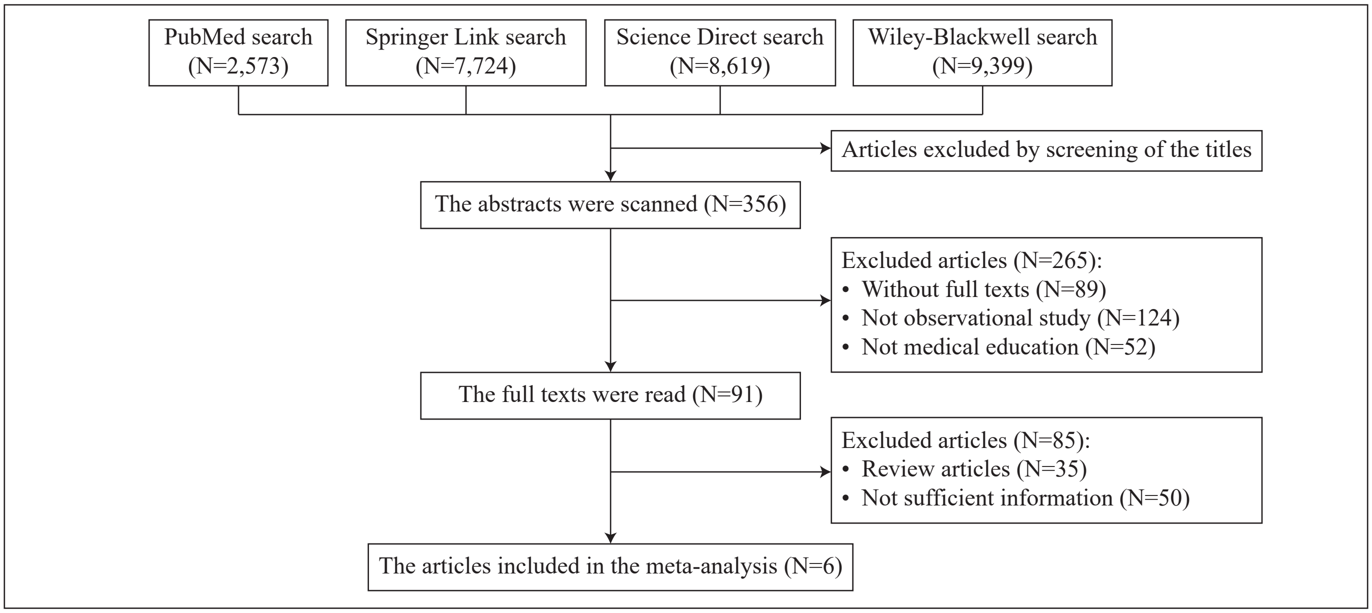

Fig. (1): PRISMA flow chart.

Table 1: Study characteristics and summary.

Study	Country	Study design	Respondents	Quality score	VR/AR events	VR/AR total	Traditional events	Traditional total
Jung *et al*. [19]	Korea	CCS	Freshmen	5	23	38	18	38
Real *et al*. [22]	USA	CCS	Postgraduates	6	171	237	139	221
Hashimoto *et al*. [18]	USA	CCS	Hospital Residents	5	14	14	8	13
Yoganathan *et al*. [10]	England	CCS	Postgraduates	5	17	20	12	20
Maytin *et al*. [20]	USA	CCS	Hospital Residents	4	4	4	2	4
Park *et al*. [21]	Canada	CCS	Postgraduates	4	1	12	0	12

***Note:** CCS = Case-Control Study; VR = Virtual Reality; AR = Augmtented Reality.*

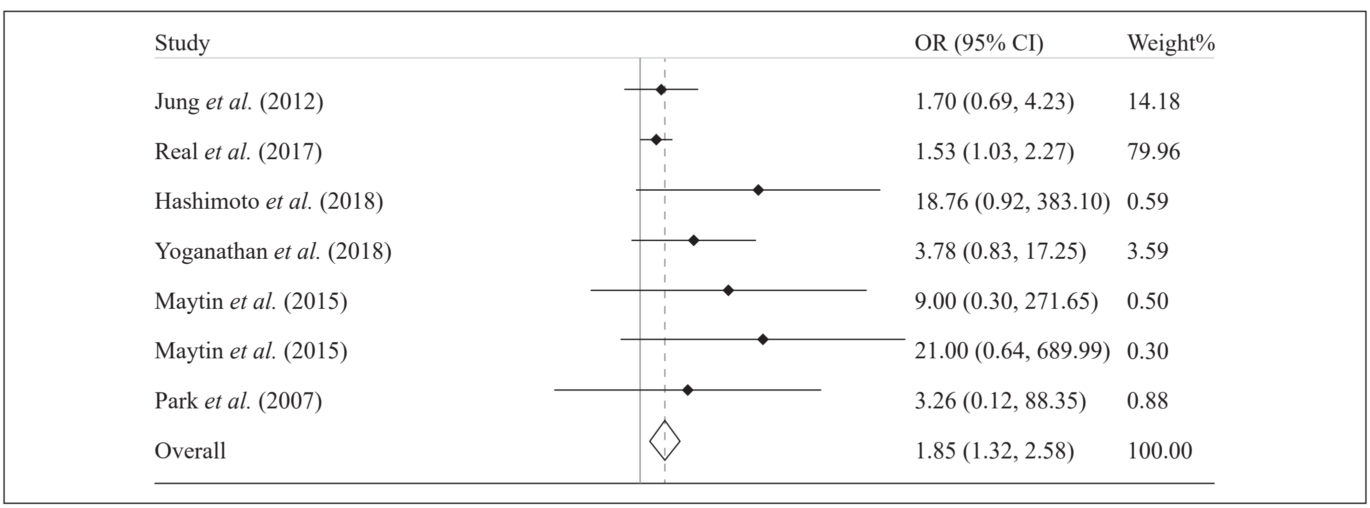

Fig. (2): Forest plot comparing VR/AR and traditional education pass rates.

Table 2: Subgroup analysis of pass rates by region and profession.

Category	Studies	OR (95% CI)	Heterogeneity (%)
Region			
North America	4 [18, 20-22]	1.79 (1.23-2.60)	31.5
England and Korea	2 [10, 19]	2.12 (0.98-4.60)	0.0
Profession			
Freshmen	1 [19]	1.70 (0.69-4.23)	-
Postgraduates	3 [10, 21, 22]	1.64 (1.13-2.39)	0.0
Hospital Residents	2 [18, 20]	15.73 (2.35-105.04)	0.0

of immersive technology training in this professional group.

Summary of Results

The overall odds ratio for pass rates in the VR group compared to the traditional education group was found to be 1.85 (95% CI: 1.32–2.58). This indicates that students trained with VR methods had significantly higher pass rates than those trained using traditional methods.

By employing these analytical tools, we were able to robustly evaluate the effectiveness of VR in medical education, providing clear insights into its benefits relative to conventional instructional methods.

DISCUSSION

According to the findings of this meta-analysis, students who received instruction through virtual reality (VR) exhibited higher pass rates compared to those taught through traditional methods. The analysis revealed a significant difference in pass rates between the two groups, with an odds ratio (OR) of 1.85 (95% CI: 1.32-2.58).

This suggests that VR training may be particularly effective for developing advanced skills and specialized knowledge. The higher pass rates observed in various countries further indicate the global applicability of VR training. Additionally, similar positive outcomes were noted across different sample sizes, demonstrating that VR can effectively accommodate diverse student groups.

These results reinforce previous research comparing VR with conventional medical education approaches, where students often reported high satisfaction levels and significant knowledge gains from VR instruction [23-26]. The immersive, three-dimensional environment and real-time feedback provided by VR appear to enhance understanding of complex concepts, such as autonomic processes [4, 6-8]. For example, students practising laparoscopic colorectal surgery in a virtual environment made fewer mistakes than they would have in real-life scenarios. This experience not only bolstered their confidence in performing tasks but also deepened their understanding of the underlying procedures [27].

However, some challenges related to VR training must be addressed. Further research is needed to determine how well the skills acquired through VR translate to clinical practice [28]. Additionally, careful design is crucial for VR applications, especially in surgical training, where the software must be intricate and precise [29]. There should also be ongoing scrutiny of whether VR can effectively replicate real-world scenarios [2].

It is important to note that the studies included in this meta-analysis were not blinded. Students were aware of whether they were receiving VR-based instruction or traditional training, which could introduce bias. One of the key strengths of our investigation was the focus on pass rates as an objective metric to compare VR and traditional education, which helps mitigate bias. Nonetheless, there are limitations to consider. The analysis included only six studies, which may weaken the generalizability of the findings. Additionally, the small sample sizes in some of the included studies could introduce bias. Finally, the geographic scope of the research was limited, suggesting a need for broader studies to confirm these results.

CONCLUSION

According to this meta-analysis. Learning medicine is made easier when virtual reality (VR) is used in medical education. As a result, the idea of fusing virtual reality with conventional instruction should be explored. We argue that virtual reality (VR) will be a major component of medical education going forward.

Quality Assessment and Publication Bias

The Newcastle-Ottawa Scale assessment showed varying quality among included studies, with scores ranging from 4 to 5, indicating moderate quality. Potential publication bias was assessed using a funnel plot and Egger's test, revealing no significant bias ($P>0.05$), suggesting that the findings are robust and reliable.

The results highlight the importance of integrating VR into medical education and encourage ongoing research in this evolving field.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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AUTHORS' CONTRIBUTION

All authors have contributed to the study design, analysis, and manuscript preparation with complete academic and scientific independence.

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