January-March 2024
Vol. 2, no. 1 / pp. 7-12

Received: November 12, 2023
Accepted: January 26, 2024

doi: 10.35366/114906

Augmented reality as a training tool for minimally invasive spine surgery

Realidad aumentada como herramienta de formación para la cirugía mínimamente invasiva de la columna vertebral

Jorge Alberto Pérez Terrazas,[*,‡,§] Daniel Sebastián Rivas Toledano,[*] Jessica Alatorre-Flores,[¶] Miguel Padilla-Castañeda,[¶] Alejandro Méndez-Viveros,[*,||] Roberto Coronado,[||] Rubén Ordoñez-Antacahua,[*,‡] Felipe Camarillo-Juárez,[*,‡] Hector Niño-Ortega[*,‡]

Keywords:
percutaneous screw placement, facet infiltration, Kambin's triangle, augmented reality, spine surgery.

Palabras clave:
colocación percutánea de tornillos, infiltración facetaria, triángulo de Kambin, realidad aumentada, cirugía de columna.

ABSTRACT

Introduction: augmented reality (AR) technologies have now reached a level of maturity suitable for numerous potential applications in the consumer market. Simulators provide the opportunity to practice and develop surgical skills in a controlled and safe environment, playing a crucial role as an educational tool. In various fields, randomized controlled trials have shown that trainees provided with three-dimensional (3D) images exhibited markedly improved identification of crucial anatomical features along with quicker response times. Minimally invasive spine surgery is considered a procedure that requires precision. The acquisition and improvement of skills required for such task, is fundamental to guarantee exquisite results, minimizing future complications. **Material and methods:** we conducted a retrospective, longitudinal, observational study with the aim of assessing spine surgery resident's learning experience with simulation systems based on augmented reality at the General Hospital of México in association with the Institute of Applied Sciences and Technology from the Autonomous National University of Mexico. The study lasted five months and included five sessions for each participant with a 1-hour duration. The protocol included an introductory phase in which relevant concepts related to each procedure were reviewed. Posteriorly serial simulations utilizing three different models were performed. Tasks evaluated during simulation included facet infiltration. Kambin's triangle identification, and screw placement accuracy. **Results:** augmented reality exhibited a significant reduction of procedure time ($p < 0.05$). Facet infiltration showed no statistical difference in terms of duration. In the same manner, accuracy in screw placement did not show a significative value ($p < 0.05$) between simulations, demonstrating that there is no difference for each group. Improvement of screw malposition was seen with both classic technique and augmented reality simulation. **Conclusions:** applied augmented reality holds great promise for expanding its presence in the realm of education. By seamlessly integrating digital content and information into real-world environments, AR has the potential to revolutionize how students learn and engage with complex concepts. However, widespread implementation in education faces certain challenges. Creating and maintaining educational and procedure standards is a significant concern to address, as it can impact the effectiveness and reliability of AR educational tools.

[*] Hospital General de México. Mexico.
[‡] Spine Surgery Department.
[§] ORCID: 0009-0003-7022-5221
[¶] Instituto de Ciencias Aplicadas y Tecnología, Universidad Nacional Autónoma de México.
[||] Neurosurgery Department.

Correspondence:
Jorge Alberto Pérez Terrazas, MD
E-mail: perezterrazas.ja@gmail.com

How to cite: Pérez TJA, Rivas TDS, Alatorre-Flores J, Padilla-Castañeda M, Méndez-Viveros A, Coronado R, et al. Augmented reality as a training tool for minimally invasive spine surgery. Cir Columna. 2024; 2 (1): 7-12. https://dx.doi.org/10.35366/114906

RESUMEN

Introducción: *las tecnologías de realidad aumentada (RA) han alcanzado ya un nivel de madurez adecuado para numerosas aplicaciones potenciales en el mercado de consumo. Los simuladores ofrecen la oportunidad de practicar y desarrollar habilidades quirúrgicas en un entorno controlado y seguro, y desempeñan un papel crucial como herramienta educativa. En diversos campos, ensayos controlados aleatorizados han demostrado que los alumnos a los que se proporcionan imágenes tridimensionales (3D) muestran una notable mejora en la identificación de características anatómicas cruciales junto con tiempos de respuesta más rápidos. La cirugía mínimamente invasiva de la columna vertebral se considera un procedimiento que requiere precisión. La adquisición y el perfeccionamiento de las habilidades necesarias para tales tareas son fundamentales para garantizar unos resultados exquisitos, minimizando las complicaciones futuras.* ***Material y métodos:*** *se realizó un estudio retrospectivo, longitudinal y observacional con el objetivo de evaluar la experiencia de aprendizaje de los residentes de cirugía de columna con sistemas de simulación basados en realidad aumentada en el Hospital General de México en asociación con el Instituto de Ciencias Aplicadas y Tecnología de la Universidad Nacional Autónoma de México. El estudio duró cinco meses e incluyó cinco sesiones para cada participante con una duración de una hora. El protocolo incluía una fase introductoria en la que se repasaron conceptos relevantes relacionados con cada procedimiento. Posteriormente, se realizaron simulaciones en serie utilizando tres modelos diferentes. Las tareas evaluadas durante la simulación incluyeron la infiltración facetaria. Identificación del triángulo de Kambin y precisión en la colocación de tornillos.* ***Resultados:*** *la realidad aumentada mostró una reducción significativa del tiempo de procedimiento ($p < 0.05$). La infiltración facetaria no mostró diferencias estadísticas en cuanto a la duración. Del mismo modo, la precisión en la colocación de tornillos no mostró un valor significativo ($p < 0.05$) entre las simulaciones, lo que demuestra que no hay diferencias para cada grupo. Se observó una mejora de la malposición de tornillos tanto con la técnica clásica como con la simulación de realidad aumentada.* ***Conclusiones:*** *la realidad aumentada aplicada es muy prometedora para ampliar su presencia en el ámbito de la educación. Al integrar a la perfección contenidos digitales e información en entornos del mundo real, la RA tiene el potencial de revolucionar la forma en que los estudiantes aprenden y se involucran con conceptos complejos. Sin embargo, su implantación generalizada en la educación se enfrenta a ciertos retos. La creación y el mantenimiento de normas educativas y de procedimiento es una preocupación importante que hay que abordar, ya que puede afectar a la eficacia y la fiabilidad de las herramientas educativas de RA.*

INTRODUCTION

The history of medical education has a long and evolving journey spanning centuries. Initially, medical knowledge was passed down through generations via observation and direct practice. As medicine advanced, various teaching methods and specialized educational institutions emerged.[1] The main goal of surgical medical education is to provide residents, the necessary tools to acquire surgical knowledge and skills, to effectively treat surgical conditions. The development of skills in residents is a crucial part of their training, and this is achieved through a combination of theoretical education, practical training, and supervised clinical experience.[2]

The classic apprenticeship model involves thorough and comprehensive education of surgeons under the guidance of a seasoned practitioner to develop these skills. Nevertheless, this model, considered the benchmark for training surgical residents, is deemed outdated for several reasons. These include its potential impact on patient comfort, the duration of procedures, the time and cost involved, as well as the potential for complications.[3]

In recent decades, there have been significant advancements in medical education. Over the last 10 years, immersive and interactive visualization technologies have become a great aid for decision making in high-risk procedures in orthopedic and neurosurgical surgery. Other applications include formulating better strategies in surgical planning or having a better understanding of case studies.[4,5]

Augmented reality, commonly known as AR, distinguishes itself from virtual reality (VR) by its emphasis on enhancing the user's real-world surroundings with supplementary information and graphical elements in real-time. Unlike VR, which immerses users in entirely artificial environments, AR centers its attention on enhancing the actual world.[6]

Augmented reality (AR) technologies have now reached a level of maturity suitable for numerous potential applications in the consumer market. The healthcare sector, as evidenced by the growing volume of publications on AR's role in surgery, medicine, and rehabilitation, exhibits a significant opportunity of enhancing existing clinical practices.[7]

The capacity to deliver authentic, contextually relevant experiences linked to the actual environment, amplify the interaction between physical and virtual content, all while maintaining a strong sense of presence, elucidates the increasing anticipation that AR and MR could find applicability in healthcare education across diverse settings.[8] An illustrative instance of the application of VR and AR within the medical domain pertains to medical education and training, with a particular focus on surgical procedures.[9]

Simulators provide the opportunity to practice and develop surgical skills in a controlled and safe environment, playing a crucial role as an educational tool. These simulators can recreate various surgical scenarios, allowing students to practice basic to advanced procedures, and allowing decision-making abilities to flourish through repetition and feedback.[10] Another advantage provided by simulators is objectively assessing the performance of students through precise calculations. The data collected in a database during training sessions can be analyzed to measure the improvement of the participants.[11]

In various fields, randomized controlled trials have shown that trainees provided with three-dimensional (3D) images exhibited markedly improved identification of crucial anatomical features along with quicker response times compared to those presented with two-dimensional (2D) images. Furthermore, these simulators provide consistent and impartial means of assessing performance metrics, which can be replicated across different trainees and over extended periods.[12]

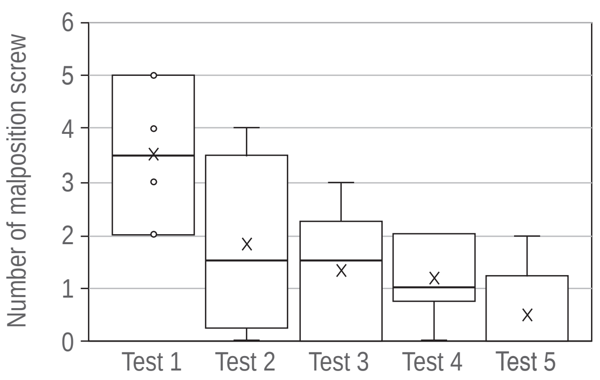

Figure 1: Malposition screw events with classic technique.

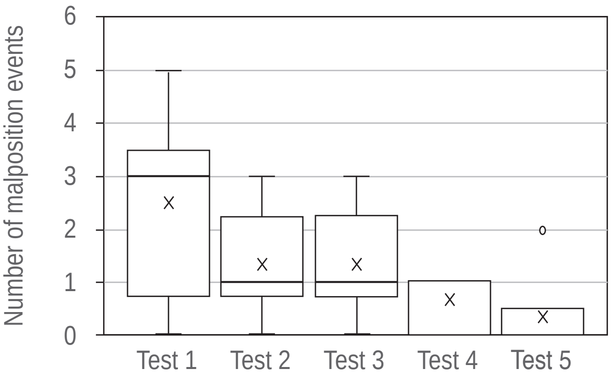

Figure 2: Malposition events with augmented reality simulation.

Minimally invasive spine surgery is considered a procedure that requires precision. The acquisition and improvement of skills required for such task, is fundamental to guarantee exquisite results, minimizing future complications. Unfortunately, the innate complexity of such, may lead to practice and feedback limitations. Thus, augmented reality simulators have come to offer a promising tool in the training field, providing a safe, controlled, and comfortable environment.

With this study we aim to describe the learning curve in spine surgery residents through the measurement and validation of skills development, in procedures such as percutaneous facet infiltration, transpedicular screw placement and Kambin's triangle identification, while analyzing the impact of simulation on the trainee's understanding of how these procedures are accomplished.

MATERIAL AND METHODS

We conducted a retrospective, longitudinal, observational study with the aim of assessing spine surgery resident's learning experience with simulation systems based on augmented reality at the General Hospital of México in association with the Institute of Applied Sciences and Technology from the Autonomous National University of Mexico. In this study a total of 14 residents were included in the sample. Participants included 3rd and 4th year trauma and orthopedics and neurosurgery residents as well as fellows. The study lasted five months and included five sessions for each participant with a 1-hour duration. The protocol included an introductory phase in which relevant concepts related to each procedure were reviewed. Posteriorly serial simulations utilizing three different models were performed.

The first model included a 3D printed piece without tissue in order to familiarize participants with relevant anatomic points. The second model, a closed model (traditional technique), encompassed a 3D printed piece located inside a tissue simulator. Finally, the third model, characterized by mixed reality, combined augmented reality with direct visualization of axial and sagittal planes of the model.

Tasks performed during simulation included facet infiltration, which was evaluated directly by the examiner, transpedicular screw placement assessed by observation of the imaging data base with posterior comparison to the Gertzbein scale; and identification of Kambin's triangle, evaluated by the time spent in this assignment and the times a participant damaged the posterior root before localization.

Data collected included resident's postgraduate year, age, sex, time of process execution, correct facet localization, correct number of screws placed, number of solicited x-rays during the procedure, and number of root lesions. A subjective confidence survey was performed before and after the simulations, to describe the individual satisfaction ratio between participants. Results were compiled, and data between the simulation with traditional technique and augmented reality were compared.

RESULTS

A distribution comparison was implemented between the two simulation conditions (traditional technique vs augmented reality technique) exhibiting a significant statistical reduction of procedure time with the augmented reality technique ($p < 0.05$).

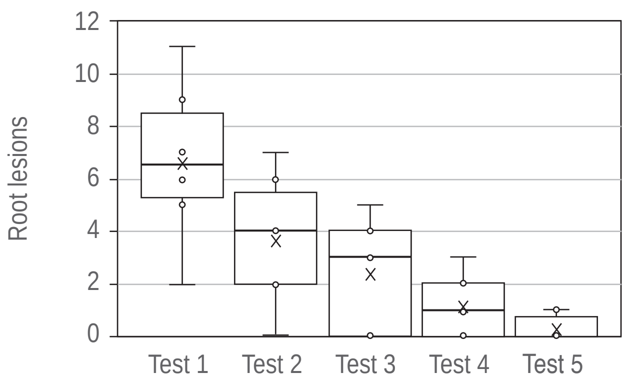

Figure 3: Progression of root lesion with classic technique.

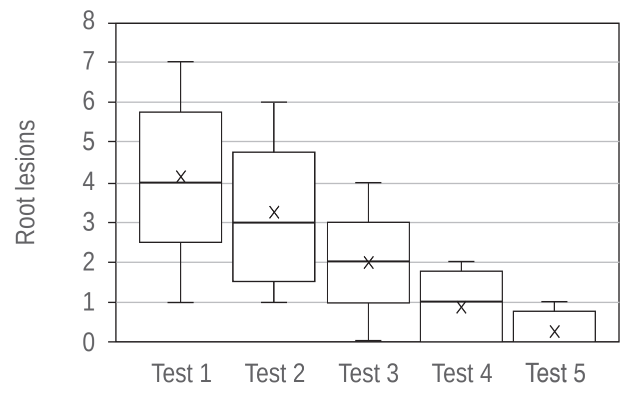

Figure 4: Progression of root lesions with AR technique.

Independent pairing was performed obtaining 3 different groups for evaluation: facet infiltration, screw placement and Kambin's triangle identification. Facet infiltration showed statistical difference in terms of duration between the traditional and augmented reality technique. In the same manner, accuracy of screw placement did not show a significative value ($p < 0.05$) between simulations, demonstrating that there is no difference in terms of precision.

Improvement of screw malposition was seen with both classic technique and augmented reality simulation. *Figures 1 and 2* show the progression of screw positioning after five tests, indicating a reduction of negative events, with the lowest incidence occurring in the augmented reality group. The time spent in screw placement showed to be shorter in the augmented reality simulation ($p < 0.05$), nevertheless, placement quality measured by the Gertzbein scale did not demonstrate to be significative different between one or another ($p > 0.05$).

Kambin's triangle identification and subsequent root lesions noticeably improved with both techniques with the advancement of serial test, showing a remarkable reduction in root lesions *(Figures 3 and 4)*. The time to identify Kambin's triangle demonstrated a significant reduction with augmented reality ($p > 0.05$), unfortunately accuracy wasn't modified by any modality ($p < 0.05$).

Radiation exposure after serial tests, was found to have a significant improvement, with a reduction of exposure in both methods, demonstrated as a personal and global progression *(Figures 5 and 6)*.

DISCUSSION

No significance was found in correct screw placement between techniques, in the same manner no significance was found in relation to facet infiltration. In a review conducted by Ghaednia et al, a similar study with screw placement in a virtual thoracic spine performed by Luciano et al, was mentioned. Results demonstrated a 15% mean score improvement in accuracy with a 50% reduction in SD from practice to test, suggesting a great benefit in novice doctors.[13,14]

The hardest perceived task was Kambin's triangle identification demonstrated by a higher rate of root lesions with the traditional technique, while the easiest task was facet infiltration. Screw placement showed to be more elaborated at L5 while Kambin's triangle presented with a more complex identification between L5 to S1. The perceived confidence of the participants improved as serial tests were conducted and the learning curve demonstrated stabilization after the 5th session.

In a review performed by McKnight et al, it is mentioned that augmented reality hasn't exhibited a definite superiority in terms of skill or knowledge retention when compared to traditional training or virtual reality (VR). In addition, when using headsets, it has been reported that users are prone to experience, headaches, dizziness, and blurred vision.[15]

Another notable concern is the rapid pace of technological advancement, which surpasses the speed at which training programs can be developed, put into practice, and rigorously tested. Consequently, by the time a simulator's effectiveness as a training tool is thoroughly evaluated, it may already be outdated.[16]

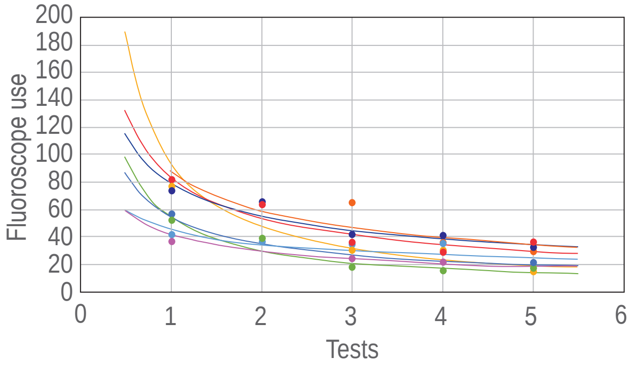

Figure 5: Radiation exposure evolution after serial tests with classic technique in each participant (represented by each color).

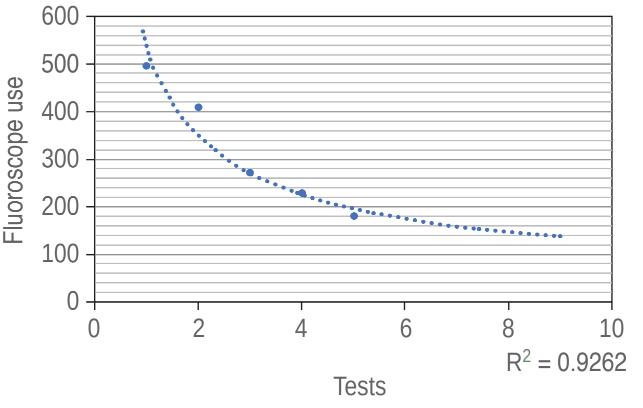

Figure 6: Global progression of fluoroscopy employment.

CONCLUSIONS

Applied augmented reality holds great promise for expanding its presence in the realm of education. By seamlessly integrating digital content and information into real-world environments, AR has the potential to revolutionize how students learn and engage with complex concepts. However, widespread implementation in education faces certain challenges, particularly the need for unified and validated systems that ensure the quality and safety of AR applications. Creating and maintaining standardized learning procedures is a significant concern to address, as it can impact the effectiveness and reliability of AR educational tools. Moreover, the costs associated with developing and implementing AR solutions can be substantial, potentially leading to under distribution, where only well-funded institutions or learners with access to high-end technology can fully benefit from this transformative educational approach. Addressing these concerns is crucial to ensure that the benefits of applied augmented reality are accessible to a broader spectrum of students and educational institutions.

REFERENCES

1. Agha RA, Fowler AJ. The role and validity of surgical simulation. Int Surg. 2015; 100: 350-357.
2. Jud L, Fotouhi J, Andronic O, Aichmair A, Osgood G, Navab N, et al. Applicability of augmented reality in orthopedic surgery - A systematic review. BMC Musculoskelet Disord. 2020; 21: 103.
3. Lungu AJ, Swinkels W, Claesen L, Tu P, Egger J, Chen X. A review on the applications of virtual reality, augmented reality and mixed reality in surgical

simulation: an extension to different kinds of surgery. Expert Rev Med Devices. 2021; 18: 47-62.
4. Batteux C, Haidar MA, Bonnet D. 3D-printed models for surgical planning in complex congenital heart diseases: a systematic review. Front Pediatr. 2019; 7: 23.
5. Mabrey JD, Reinig KD, Cannon WD. Virtual reality in orthopaedics: is it a reality? Clin Orthop Relat Res. 2010; 468: 2586-2591.
6. Hu HZ, Feng XB, Shao ZW, Xie M, Xu S, Wu XH, et al. Application and prospect of mixed reality technology in medical field. Curr Med Sci. 2019; 39: 1-6.
7. Ferrari V, Klinker G, Cutolo F. Augmented reality in healthcare. J Healthc Eng. 2019; 2019: 9321535.
8. Gerup J, Soerensen CB, Dieckmann P. Augmented reality and mixed reality for healthcare education beyond surgery: an integrative review. Int J Med Educ. 2020; 11: 1-18.
9. Yeung AWK, Tosevska A, Klager E, Eibensteiner F, Laxar D, Stoyanov J, et al. Virtual and augmented reality applications in medicine: analysis of the scientific literature. J Med Internet Res. 2021; 23: e25499.
10. Cooper JB, Taqueti VR. A brief history of the development of mannequin simulators for clinical education and training. Qual Saf Health Care. 2004; 13: i11-i18.
11. Gaba DM. The future vision of simulation in health care. Qual Saf Health Care. 2004; 13 Suppl 1: i2-i10.
12. Cao C, Cerfolio RJ. Virtual or augmented reality to enhance surgical education and surgical planning. Thorac Surg Clin. 2019; 29: 329-337.
13. Ghaednia H, Fourman MS, Lans A, Detels K, Dijkstra H, Lloyd S et al. Augmented and virtual reality in spine surgery, current applications and future potentials. Spine J. 2021; 21: 1617-1625.
14. Luciano CJ, Banerjee PP, Bellotte B, Oh GM, Lemole M Jr, Charbel FT, et al. Learning retention of thoracic pedicle screw placement using a high-resolution augmented reality simulator with haptic feedback. Neurosurgery. 2011; 69: ons14-9; discussion ons19.
15. McKnight RR, Pean CA, Buck JS, Hwang JS, Hsu JR, Pierrie SN. Virtual reality and augmented reality-translating surgical training into surgical technique. Curr Rev Musculoskelet Med. 2020; 13: 663-674.
16. Keenan ID, Powell M. Interdimensional travel: visualisation of 3D-2D transitions in anatomy learning. Adv Exp Med Biol. 2020; 1235: 103-116.

Conflict of interest: we do not have a conflict of interest.