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ORIGINAL

Comparative Analysis of Virtual Reality Simulation and Conventional Training in Temporal Bone Dissection

Análisis comparativo de la simulación de realidad virtual y el entrenamiento convencional en disección ósea temporal

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ABSTRACT

A novel method for teaching a variety of medical operations is virtual reality (VR) simulation, which can potentially improve learning without the hazards of conventional hands-on training. A crucial ability in otolaryngology that calls for accuracy and skill is the dissection of cadaveric temporal bones. A total of 155 individuals with little to no prior knowledge of temporal bone dissection were randomized to either the VR group (85 participants), which trained under supervision using a VR simulator, or the traditional group (70 participants), which used models, videos, and small group instructions. Participants dissected a cadaveric temporal bone after training, and blinded assessors evaluated the results using six criteria: anatomical accuracy, technique, efficiency, overall performance, injury size, and end product. The results revealed that the VR group outperformed the traditional group, achieving significantly higher scores in the end product, causing fewer injuries to anatomical structures, and demonstrating better overall performance, with all differences being statistically significant. The research employed IBM SPSS statistics (version 26) for statistical analysis, and an independent t-test was used to compare the groups' mean scores. The results indicated fair to moderate reliability when inter-rater reliability was evaluated using the Intra-class Correlation Coefficient (ICC) and the kappa statistic. These findings suggest that VR simulation is a more effective means of honing cadaveric temporal bone dissection abilities than traditional training techniques.

Keywords: Virtual Reality (VR); Temporal Bone Dissection; Small Group Tutorials; Blinded Assessors; Anatomical Structures.

RESUMEN

Un método novedoso para enseñar diversas operaciones médicas es la simulación de realidad virtual (RV), que puede mejorar potencialmente el aprendizaje sin los peligros de la formación práctica convencional. Una habilidad crucial en otorrinolaringología que requiere precisión y destreza es la disección de huesos temporales cadavéricos. Un total de 155 personas con escasos o nulos conocimientos previos de disección de huesos temporales fueron asignadas aleatoriamente al grupo de RV (85 participantes), que se entrenó bajo supervisión utilizando un simulador de RV, o al grupo tradicional (70 participantes), que utilizó modelos, vídeos e instrucciones en grupos reducidos. Los participantes diseccionaron un hueso temporal cadavérico después del entrenamiento, y evaluadores ciegos evaluaron los resultados utilizando seis criterios: precisión anatómica, técnica, eficiencia, rendimiento general, tamaño de la lesión y producto final. Los resultados revelaron que el grupo de RV superó al grupo tradicional, logrando puntuaciones significativamente más altas en el producto final, causando menos lesiones en las estructuras anatómicas y demostrando un mejor

rendimiento general, siendo todas las diferencias estadísticamente significativas. Para el análisis estadístico se utilizó el programa estadístico IBM SPSS (versión 26), y para comparar las puntuaciones medias de los grupos se empleó una prueba t independiente. Los resultados indicaron una fiabilidad entre aceptable y moderada cuando se evaluó la fiabilidad entre evaluadores mediante el coeficiente de correlación intraclase (CCI) y el estadístico kappa. Estos resultados sugieren que la simulación de RV es un medio más eficaz para perfeccionar las habilidades de disección cadavérica del hueso temporal que las técnicas de formación tradicionales.

Palabras clave: Realidad Virtual (RV); Disección del Hueso Temporal; Tutorías en Grupos Pequeños; Evaluadores Ciegos; Estructuras Anatómicas.

INTRODUCTION

A key element of the healthcare sector that ensures the best possible training for upcoming generations of surgeons is surgical education. For a variety of reasons, a significant amount of surgical skills training has moved from operating rooms to skills labs and simulators.[1] One teaching tool for temporal bone dissection in otorhinolaryngology training is a high-fidelity cadaveric temporal bone. Even though cadaver temporal bones are indeed the most reliable method of simulating training for temporal bone surgery, more training aids are currently being researched due to their growing scarcity globally.[2] Unsupervised cervical bone drilling has the potential drawback of trainees learning insufficient skills, which could result in the inefficient use of limited cadaveric chronological bones, despite the fact that practicing chronological bone drilling on cadaveric temporal bones is essential for knowledge and skill acquisition. A potential supplemental training technology that could be able to help with some of these present training challenges is Virtual Reality (VR) simulation.[3] VR simulation has been acknowledged as a valuable instrument for surgical education. A recent Cochrane research indicated that VR laparoscopic simulators improved operational performance. [4] It has been demonstrated that the Endoscopic Sinus Surgical Simulator significantly improves trainees' early operative performance in endoscopic sinus surgery. With the number of surgeries performed being unconstrained by the number of patients or the availability of cadaveric temporal bones, a significant advantage of VR simulation training is that it offers a consistent, repeating setting for efficient, repeated instruction.[5] Simulators preserve valuable teaching resources, such as cadaver bones, and give junior trainees hands-on experience early in their surgical training.[6] This would ultimately make greater use of the temporal bones of the cadaver and free up the time of attending surgeons to supervise the more complex aspects of surgical judgment and decision-making. Previous investigations have demonstrated the facial and contemporaneous validity of VR temporal bone simulators.[7]

Numerous medical applications have lately been made possible by consumer-grade VR, but more evidence was required to confirm their viability. In a VR context, the accuracy of temporal bone-based simulated surgical planning was contrasted with that of traditional cross-sectional picture viewing via the interface.[8] Every neurosurgical trainee faces the difficult but crucial task of learning complex neuroanatomy. Many modalities have been developed to help individuals learn architecture as technology has progressed. The purpose of this research was to evaluate the instructional effectiveness of a 3D virtual temporal skeleton model.[9] The research's goal was to examine various approaches for temporal bone surgical anatomy segmentation for patient-specific virtual reality simulation.[10] Although it took a lot of time, manual segmentation offered the greatest flexibility. Because there was less human engagement, the atlas-based automated segmentation has the potential to segment a wide variety of structures and generate segmentations that are comparable to manual partitioning, with the acceptable processing time. Temporal Bone (TB) cadaver dissection abilities can be enhanced through VR simulation training, and distributed self-regulated practice was best for consolidating skills. It is uncertain that Decentralized Training (DT) affects TB surgical training. The way subsequent cadaver dissection performance was affected by decentralized VR simulation training in TB surgery was examined in this research.[11] Recent advancements in extended reality technologies have piqued medical attention. The author of the research looked at the use of patient-specific VR bone temporal models for anatomical education, pre-operative surgical planning, and intraoperative surgical referencing.[12] The potential of this cutting-edge surgical adjunctive tool was further demonstrated by the pre- and intra-operative applications.

The learning curves for Cochlear Implant (CI) surgery in VR Simulation-Based Training (SBT) and the allocation of abilities to a 3D-printed model were investigated in this research.[13] Novices' performance is improved with VR SBT of CI surgery. It helped to introduce the process and learn the fundamentals. Before cadaveric or real-life surgery, CI surgical training should focus on objective performance evaluation to achieve predetermined competency. Initial training can be conducted in a controlled and secure setting via simulation-based training. The 3D System's Geomagic Touch Haptic Device served as the model for the VR system. In

order to assess the VR temporal skeletal surgery simulator in an Antro anti-mastoidectomy simulation, this analysis was necessary.[14] Three VR simulation training sessions were included in the prospective research design. The length of a VR session, performance quality, and the number of errors (negative points) were used to evaluate each simulation. The duration of the performance was shortened during subsequent VR sessions, and there was also an improvement in performance quality and a decrease in errors. A high-quality, reasonably priced supplement to conventional training techniques was provided by the VR temporal bone surgery simulator CardinalSim. Establishing CardinalSim's face and content validity through a nationwide assessment was the aim of this investigation.[15] Several materials and production techniques were compared to evaluate the accuracy of 3D-printed TB representations in simulating cortical mastoidectomy.[16] To determine which 3D-printing methods offer the most realistic surgical training experience, the haptic feedback and anatomical accuracy of different TB models during surgical drilling was evaluated. The aim was to improve on the existing ABS-based models by comparing them head-to-head to identify the best prototypes for skull base surgical training.

The purpose of this research is to evaluate that medical students learn cadaveric temporal bone dissection using VR simulation training against more conventional teaching techniques. Evaluating the disparities between the two groups' performance is the main goal. The research also examines how VR-based training affects learning retention and skill acquisition.

METHOD

In this research, 155 medical students were assigned to participate in the VR Training Group (VRTG) (n = 85) or the Traditional Training Group (TTG) (n = 70) for training in temporal bone dissection. TTG practiced cadaveric dissection under the guidance of an instructor, while VRTG employed a specialized VR simulator that offered real-time feedback. To ensure a thorough comparison of training efficiency, statistical analysis was conducted using independent t-tests, Kappa Statistic, and Intra-Class Correlation Coefficient (ICC).

Data collection

Table 1. Demographic data analysis

Variables	VR Training Group (VRTG) (n=85)	Traditional Training Group (TTG) (n=70)
Age group (years)		
24-27	32 (37,6 %)	28 (40,0 %)
28-31	38 (44,7 %)	30 (42,9 %)
32-34	15 (17,7 %)	12 (17,1 %)
Gender		
Male	49 (57,6 %)	40 (57,1 %)
Female	36 (42,4 %)	30 (42,9 %)
Educational background		
Bachelors in Medicine (MBBS)	44 (51,8 %)	38 (54,3 %)
Postgraduate (MS/MD in Surgery)	41 (48,2 %)	32 (45,7 %)
Handedness		
Right-Handed	74 (87,1 %)	61 (87,1 %)
Left-Handed	11 (12,9 %)	9 (12,9 %)
Dominant Eye		
Right-Eye Dominant	67 (78,8 %)	54 (77,1 %)
Left-Eye Dominant	18 (21,2 %)	16 (22,9 %)
Prior Surgical Experience		
No Prior Experience	71 (83,5 %)	58 (82,9 %)
Minimal Experience (1-2 dissections)	14 (16,5 %)	12 (17,1 %)
Pre-existing Conditions		
Myopia (> -2,0 D)	22 (25,9 %)	19 (27,1 %)
Hypertension	48 (56,4 %)	37 (52,8 %)
Diabetes	15 (17,6 %)	14 (20 %)

To gather data for this research, 155 medical students were enlisted and randomized to either the VRTG (n=85) or the TTG (n=70). The demographic data of the participants was documented, including their age, gender, educational background, dominant eye, handedness, previous surgical experience, and pre-existing conditions. The research required to evaluate VR simulation's efficacy in temporal bone dissection in comparison to conventional techniques. The information ensures a thorough comparison of the two training approaches.

Selection criteria

This process ensures a consistent and accurate comparison between VR and traditional training techniques.

Inclusion criteria

- Medical Students: To ensure the proper degree of understanding for temporal bone dissection, only medical students participating in an accredited medical program are allowed.
- Minimal Dissection Experience: To ensure a fair baseline for both groups, participants should have little to no prior experience dissecting temporal bones (no more than two dissections).
- Age Range: To maintain consistency in cognitive and physical ability between groups, participants must be between the ages of 24 and 35.
- Informed Consent: To ensure ethical compliance, participants must give written informed consent before beginning the research.

Exclusion criteria

- Visual or neurological impairments: People with disorders that impact visual acuity, hand-eye coordination, or cognitive function, as they could impede performance.
- Non-Healthy Participants: Participants who could be unable to participate due to serious medical issues, including diabetes, uncontrolled hypertension, or other chronic illnesses.
- Non-Volunteers: Individuals who are unable to dedicate themselves to the entire research period, guaranteeing uniformity in instruction and assessment.

Group splitting

The 155 participants were divided into two groups: the TTG, which conducted hands-on cadaveric dissection under the supervision of an instructor, and the VRTG, which practiced using a VR simulator. A comparison of the two training approaches on temporal bone dissection skills was made possible by this division.

VR Training Group (VRTG)

A VR simulator dedicated to temporal bone dissection delivered supervised training to the 85 participants who belonged to the VRTG. This group received access to a simulated controlled environment that replicated real dissection techniques for repeated practice purposes. During step-by-step training, the VR system supplied performance indicators and real-time feedback to the participants. VR technology enabled the participants to develop multiple skills without encountering any risks or experiencing physical danger. The researchers conducted experiments to determine whether VR technology would improve students' anatomical accuracy and dissection abilities.

Traditional Training Group (TTG)

The TTG enrolled 70 trainees for practical experience, including anatomical models combined with instructional videos and practical tutorials and examination of cadaveric specimens. Students in this group followed a conventional educational approach through direct cadaver dissection activities. Participants receive instructor direction and feedback as instructors help them develop their abilities through direct hands-on activities. The research team pursued the evaluation of traditional practical methods that teach temporal bone dissection procedures. The standard for evaluating the VRTG was based on measuring this group's performance indicators.

Temporal Bone Dissection Training with Virtual Reality Simulation

Medical students can learn temporal bone dissection techniques in an immersive VR environment through simulation practices that organize away with the necessity of working with cadavers. The dedicated VR simulator lets participants practice their virtual dissections while both therapists and trainees provide immediate assistance regarding proper technique as well as exact anatomical precision. Students can learn accuracy together with confidence for actual dissection through multiple practice sessions in this virtual training that provides a safe condition. Virtual exploration of the temporal bone was possible through the simulator because it duplicated actual anatomical features. The VR system enhances learning through its built-in performance monitoring and tracking capabilities. The VR simulation platform delivers a protected adaptable educational system that works at scale to replace conventional cadaver-based teaching methods.

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Statistical analysis

Statistical testing of VR simulation training against conventional temporal bone dissection methods occurred through IBM SPSS Statistics version 26. The research used an independent t-test to measure differences between scores acquired from regular TTG participants versus the VRTG participant pool. Statistics employed the test to confirm at P < 0,05 significance levels, the variations that existed between performance parameters, including end product quality alongside anatomical injuries and overall performance. The Kappa Statistic determined the inter-rater score reliability between evaluators. Gas provided a measurement technique that determined how accurately multiple blinded raters agreed on the assessment ratings of participant performance. The ICC assesses the reliability of assessors who rate performance on a continuous scale by evaluating their consistency and dependability. The ICC showed fair to moderate reliability levels in the assessment of numerical scores by different evaluators. The research was able to conduct an unbiased VRTG and TTG assessment of temporal bone dissection procedures based on these statistical evaluation methods.

RESULTS AND DISCUSSION

This research examined VRTG and TTG's impact on cadaveric temporal bone dissection performed by medical students. The evaluation results showed that the VRTG outperformed the TTG in every performance category, including overall evaluation, technique, efficiency, anatomical accuracy, damage size, and end product quality.

Effects of an Independent T-test on the Effect of VR Simulation on Temporal Bone Dissection

The independent t-test was used to analyze the temporal bone dissection performance scores between the VRTG and TTG groups. The research examined statistical significance through the execution of this statistical test when investigating performance observations. The evaluation showed statistically relevant differences (p < 0,001 for all parameters) between groups in every area, including total performance and technical abilities efficiency level and end product quality (table 2 and figure 1). The higher score of the VRTG demonstrates improved performance along with greater precision during dissection indicated by minimal damage size. VR simulation proves more effective compared to standard training techniques for developing cadaveric temporal bone dissection abilities according to experimental outcomes.

Table 2. Analysis of training effectiveness

Evaluation criteria	VR Training Group (VRTG) (Mean ± SD)	Traditional Training Group (TTG) (Mean ± SD)	t-value	df	p-value
End Product Score (0-10)	8,7 ± 1,2	6,3 ± 1,5	7,21	153	<0,001
Injury Size (mm^2)	2,5 ± 0,8	4,7 ± 1,2	-8,34	153	<0,001
Overall Performance (0-10)	8,5 ± 1,1	6,1 ± 1,4	7,89	153	<0,001
Technique Score (0-10)	7,9 ± 1,3	6,8 ± 1,5	5,21	153	<0,001
Efficiency Score (0-10)	8,3 ± 1,0	6,0 ± 1,6	6,85	153	<0,001
Anatomical Accuracy (0-10)	8,6 ± 1,2	6,5 ± 1,4	7,12	153	<0,001

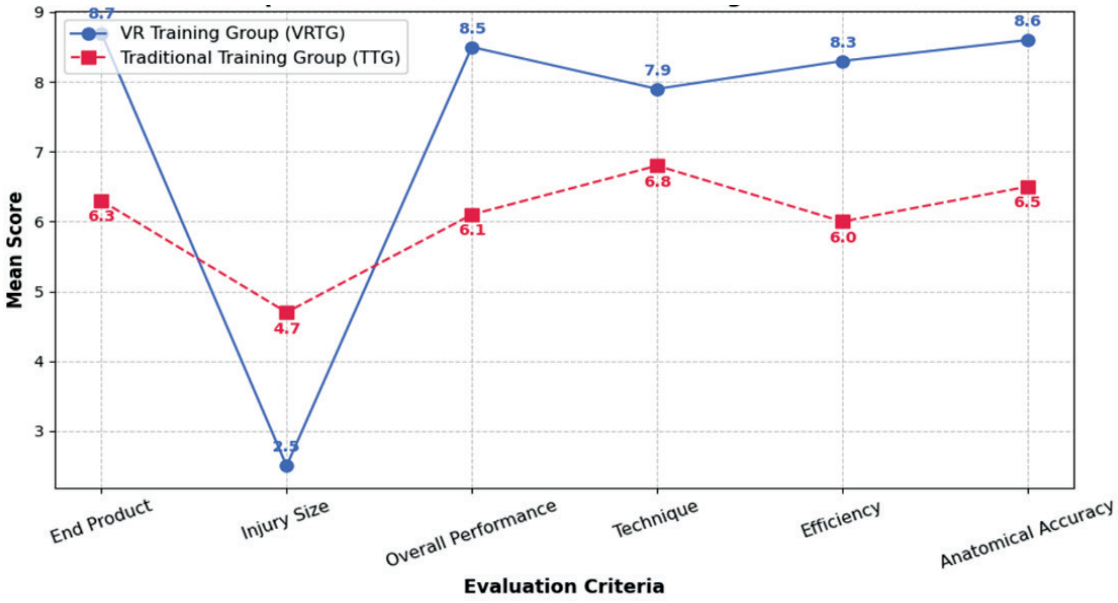

Figure 1. Performance Comparison of VR and Traditional Training in Temporal Bone Dissection

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Evaluation of Inter-Rater Reliability in VR and Conventional Groups Using the Kappa Statistic

In this research, the inter-rater reliability of evaluators assessing cadaveric temporal bone dissections was evaluated using the Kappa Statistic. This metric minimizes subjective biases by guaranteeing that the assessment criteria were applied uniformly across the VRTG and TTG. The VRTG's κ values (≥ 0,80) show a high degree of assessor scoring consistency is presented in table 3 and figure 2. The results indicate that, in comparison to traditional training methods, VR simulation training not only enhances performance but also guarantees more consistent and reliable evaluation of cadaveric temporal bone dissection skills. The VRTG's higher inter-rater reliability further supports the efficacy and consistency of VR-based learning, which makes it an excellent approach for surgical skill acquisition in otolaryngology training.

Table 3. Kappa Statistic Analysis to evaluate Consistency between Groups

Variables	VR Training Group (VRTG)		Traditional Training Group (TTG)		p-value
	Kappa (K) value	95 % CI	Kappa(K)value	95 % CI	
End Product Score	0,82	0,76-0,88	0,74	0,68-0,80	<0,001
Injury Size	0,81	0,75-0,87	0,70	0,64-0,76	<0,001
Overall Performance	0,83	0,77-0,89	0,76	0,70-0,82	<0,001
Technique Score	0,80	0,74-0,86	0,66	0,60-0,72	<0,001
Efficiency Score	0,84	0,78-0,90	0,72	0,66-0,78	<0,001
Anatomical Accuracy	0,81	0,75-0,87	0,70	0,64-0,76	<0,001

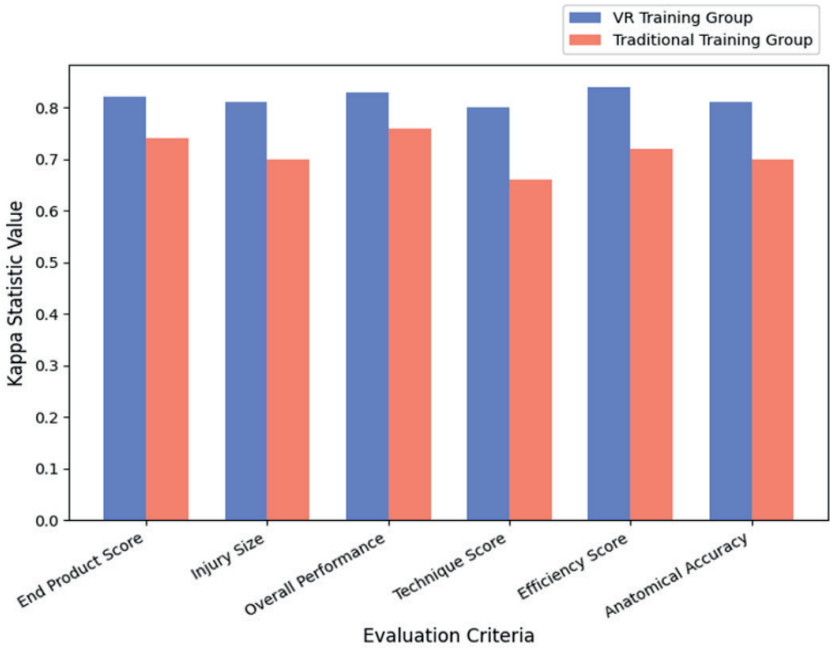

Figure 2. Comparison of Training Groups' Kappa Statistics

Employing Intra-Class Correlation Coefficient (ICC) Analysis to Ensure the Validity of Assessments in Virtual Reality and Conventional Training Participants

This research evaluated cadaveric temporal bone dissection rating consistency by evaluating assessor reliability using ICCs. The system enables objective performance assessment because different evaluators are required to use the same score evaluation systems for VRTG and TTG were represented in table 4 and figure 3. Assessors who used the VRTG achieved consistent and accurate ratings, which received an excellent ICC value of 0,85. For the conventional group, the reliability level reached moderate (0,70 ≤ ICC < 0,80) yet demonstrated some disparity in scoring assessments. The reliability of the VRTG assessment shows heightened reproducibility through F-statistics that demonstrate a significant difference in comparison to the TTG assessment reliability levels. The research demonstrates that VR simulation proves superior over traditional techniques as a method to boost cadaveric temporal bone dissection abilities among medical trainees. VR-based learning demonstrates additional advantages through better assessment results reliability because they provide standardized skill acquisition and ensure consistent evaluations.

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Table 4. Assessor Agreement Comparison within TTG Temporal Bone Dissection Training and VRTG Using ICC

Variables	VR Training Group (VRTG)		Traditional Training Group (TTG)		F-statistic value	p-value	Reliability interpretation
	ICC Value	95 % CI	ICC Value	95 % CI			
End Product Score	0,89	0,85-0,93	0,78	0,72-0,84	5,32	<0,001	VRTG improves reliability
Injury Size	0,87	0,83-0,91	0,76	0,70-0,82	4,89	<0,001	VRTG reduces assessor variability
Overall Performance	0,91	0,87-0,95	0,79	0,73-0,85	6,02	<0,001	VRTG ensures higher assessment consistency
Technique Score	0,86	0,82-0,90	0,74	0,68-0,80	4,65	<0,001	TTG shows moderate reliability
Efficiency Score	0,90	0,86-0,94	0,77	0,71-0,83	5,78	<0,001	VRTG has more standardized evaluations
Anatomical Accuracy	0,88	0,84-0,92	0,75	0,69-0,81	5,01	<0,001	VRTG enhances precision in the evaluation

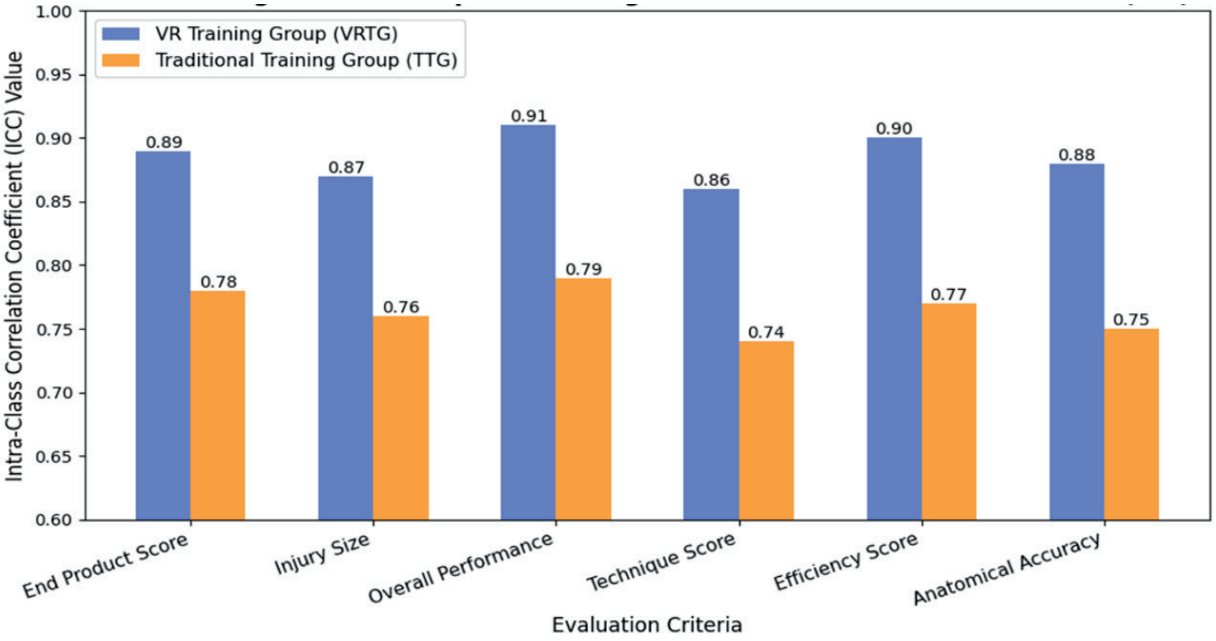

Figure 3. Training Comparison Using Intra-Class Correlation Coefficient (ICC)

DISCUSSION

The medical students who performed their dissections of temporal bones in cadavers when using VRTG or TTG systems were examined in this research. Test results establish that VRTG supplies superior training performance when compared to TTG approaches during cadaveric temporal bone dissection. The VRTG performance effectiveness along with decreased patient injuries signifies that simulated interactive training environments enhance surgical precision. Standardization of skill acquisition becomes more successful through VR-based training because of its demonstrated high inter-rater reliability and evaluation consistency. The VRTG functions well as a surgical education tool because it enhances evaluation consistency, which in turn reduces performance assessment variability. The findings validate that VR simulation contributes to medical education by delivering an organized educational experience that produces repeatable results while maintaining a high student interest level.

CONCLUSIONS

To evaluate which instructional method resulted in superior temporal bone dissection learning efficiency between VRTG and TTG for medical students was the objective of this research. The VRTG achieved better examination outcomes than the TTG in every evaluation measure ($p < 0,001$) and consistently improved performances for injury size along with anatomical accuracy and efficiency as well as technique and end product quality. The reliable assessment process of the VRTG is supported by assessing agreement, with ICC values above 0,85 accompanied by inter-rater reliability κ values above 0,80. VR simulation has emerged as a standardized

method for delivering dependable training that produces superior results compared to conventional approaches for surgical skill education. Academia, which includes otologic surgery, can achieve superior levels of trainee effectiveness and standardized performance and general operative competence via the integration of VR-based educational techniques. The small number of participants and the lack of long-term assessments of residual surgical competence were two significant limitations of this research. Future research dedicated to enhancing VR-based surgical training must focus on building larger participant groups obtaining multi-center study results and adding haptic feedback systems.

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FINANCING

None.

CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

AUTHORSHIP CONTRIBUTION

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