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Enhancing Radiology Education Through Immersive Virtual Reality: A Comparative Study Of 2D DICOM And 3D Neuroanatomical Models

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Abstract
This study investigates the effectiveness of Virtual Reality (VR) in enhancing radiology education by comparing students interpretation of neuroanatomical cases using traditional 2D DICOM images versus immersive 3D models. A within-subjects quantitative design was employed, involving 28 postgraduate students enrolled in the master's program in Radiology and Imaging Technology at Jamia Hamdard. Participants engaged with five anonymized neuro cases using the Immersive Education *VR platform, which enabled interactive visualization of both 2D images and high-resolution 3D anatomical models. The assessment was conducted using standardized questions designed to evaluate anatomical comprehension, spatial reasoning, and diagnostic accuracy. Findings demonstrated that the use of immersive 3D models significantly improved students' understanding of complex neuroanatomy and enhanced diagnostic performance compared to traditional 2D methods. These results support the integration of VR-based immersive learning tools in radiology education to foster deeper anatomical insight and clinical interpretation skills.*

Keywords: *Virtual Reality (VR), Radiology Education, Medical Imaging Technology, 3D Anatomical Visualization, Diagnostic Accuracy, DICOM Images, Neuroanatomy Interpretation.*

INTRODUCTION

Medical imaging plays an important role in diagnostic medicine, with radiological interpretation traditionally relying on two-dimensional (2D) DICOM (Digital Imaging and Communications in Medicine) images. However, 2D imaging often presents limitations in accurately visualizing complex anatomical relationships, requiring significant spatial awareness and expert interpretive skills to translate flat images into three-dimensional understanding [1,2].

In response to these challenges, Virtual Reality (VR) has emerged as an innovative educational modality, offering immersive and interactive environments where learners can explore 3D anatomical structures with a sense of depth, orientation, and scale [3–5]. Radiology educators are increasingly adopting VR technologies to enhance conceptual understanding, procedural simulation, and clinical reasoning skills [6–8].

Multiple studies, including meta-analyses and randomized trials, have demonstrated that VR-enhanced learning improves knowledge retention, spatial cognition, and learner engagement compared to traditional methods [9–11]. Furthermore, VR-based simulations allow students to safely rehearse radiological procedures and pathology identification without radiation exposure, enabling repeatable and low-risk practice environments [12,13].
Despite the growing interest and promising outcomes, current literature underscores the need for more robust, longitudinal studies to validate the pedagogical effectiveness and clinical applicability of VR in radiology education across diverse learner populations and institutional settings [14,15].

Figure 1 Virtual reality headset

Figure 2Virtual reality headset

METHODOLOGY

Study Design: This study employed a quantitative, within-subjects comparative design to evaluate the effectiveness of Virtual Reality (VR) in radiology education. The research compared postgraduate students' understanding and diagnostic performance when interpreting neuroanatomical cases using conventional two-dimensional (2D) DICOM (Digital Imaging and Communications in Medicine) images versus immersive three-dimensional (3D) models in a VR environment.

Participants: Twenty-eight postgraduate students enrolled in the master's program in Radiology and Imaging Technology at Jamia Hamdard, New Delhi, participated in the study. Participation was voluntary, and informed written consent was obtained from all students. Prior experience with VR technology was not required.

Educational Tool: The VR-based learning experience was delivered using Immersive Education, a commercially available application hosted on the Immersive Touch platform. The software provides high-resolution, patient-specific 3D neuroanatomical models for interactive exploration within a VR environment, using compatible head-mounted displays.

MATERIALS

- **Neuroanatomical Cases**: Five anonymized clinical neurovascular cases were selected. Each included 2D DICOM images and 3D VR-rendered models.
- **2D DICOM Images**: Viewed within the Immersive Education interface using traditional flat-screen mode.
- **3D VR Models**: Explored using a VR headset in an immersive environment.
- **Assessment Instruments**: Each case was paired with standardized multiple-choice and short-answer questions targeting anatomical comprehension, spatial reasoning, and diagnostic accuracy.

Sample Assessment Questions: Examples of questions included:
– "Identify the anatomical location of the aneurysm."
– "Which modality provided clearer spatial visualization?"
– "Is there evidence of ventricular involvement?"
(The complete question set is provided in the Appendix.)

Data Collection and Analysis: Participant responses were scored quantitatively. For each case, performance under the 2D and 3D conditions was compared using paired t-tests. In instances of non-normal data distribution, the Wilcoxon signed-rank test was applied. Statistical significance was determined at $p < 0.05$.
A post-experience survey was also administered to collect students' subjective feedback regarding clarity, engagement, ease of use, and modality preference.
Ethical Considerations: Ethical approval was granted by the Institutional Ethics Committee of Jamia Hamdard, New Delhi. The study adhered to the principles of the Declaration of Helsinki. Participation was voluntary, responses were anonymized, and all data were stored securely in accordance with institutional data protection protocols.

Figure 3Immersivetouch Education Module

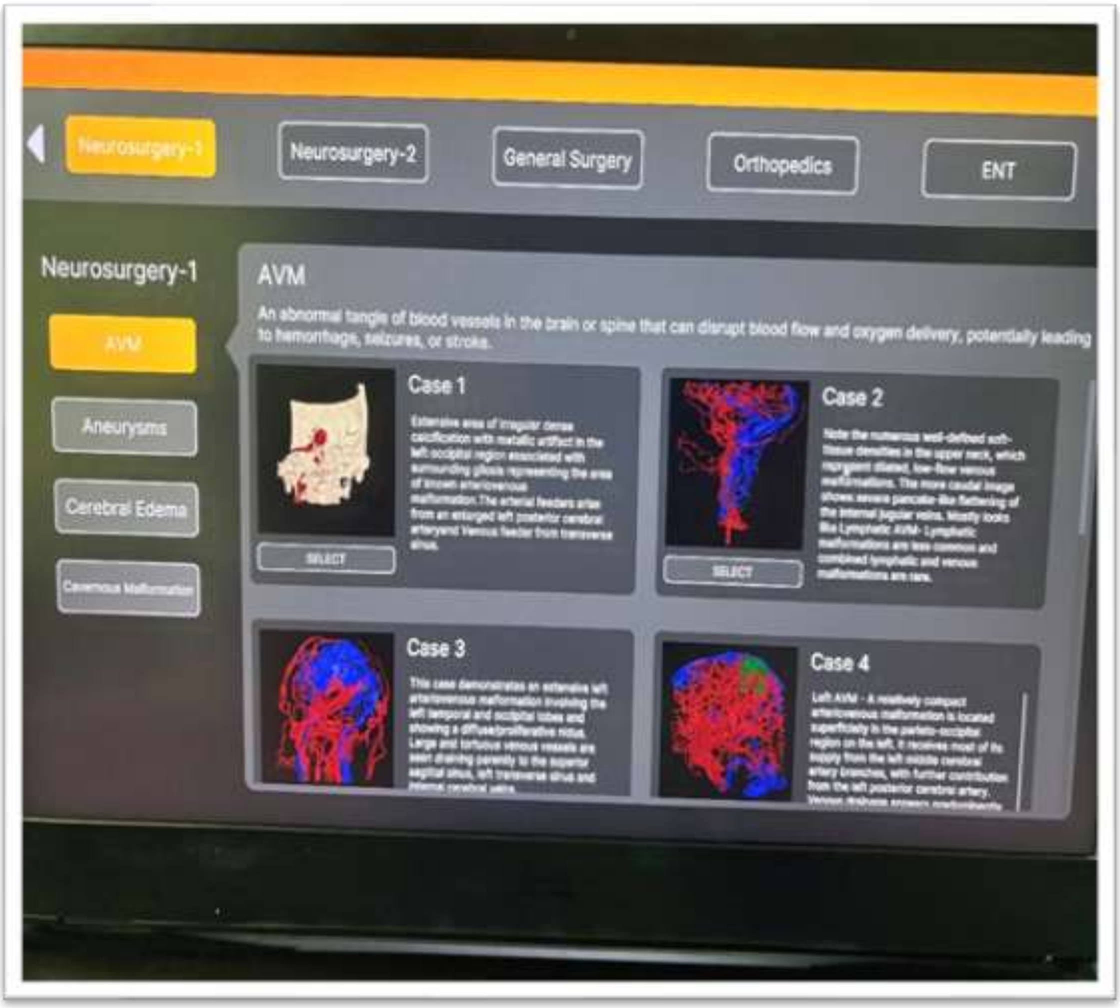


Figure 4Immersive Touch Education Module

RESULT

A total of 28 postgraduate students in Radiology and Imaging Technology participated in the study. Each student was presented with 5 neuroimaging cases, with two interpretation-based questions per case. The cases were first reviewed using conventional 2D DICOM images and then followed by a review using 3D VR models with the help of VR Headset.

QUANTITATIVE ANALYSIS OF 2D DICOM DATA

There were 5 neurology cases given to the students of different pathology,

Sr.no	No of Cases	Response Given by Participants	NO of Response
1	CASE 1	BASILAR ARTERY	8
2		MCA	20
3	CASE 2	BOTH ICA	4
4		RIGHT ICA	14
5		RIGHT MCA	7
6		RT ICA/MCA	3
7	CASE 3	ACA AND VENOUS SINUS	8
8		MCA AND VENOUS SINUS	4
9		VENOUS SINUS	9
10		All OF THE ABOVE	7

11	CASE 4	ALL VENTRICLE	10
12		LATERAL/FOURTH	2
13		LATERAL VENTRICLE	1
14		LATERAL/ THIRD	15
15	CASE 5	ABSENT	11
16		INDETERMINATE	8
17		PRESENT	9

Case 1

In first case Students are asked to Identify the location of Intracranial Aneurysm present at left middle cerebral artery, When the 2D DICOM is shown using Immersive Education module, out of 28 students only 20 students correctly Identify the location of the aneurysm and 8 student was unsure and selected Basilar artery which was incorrect.

Figure 5 Immersive Education Window case 1

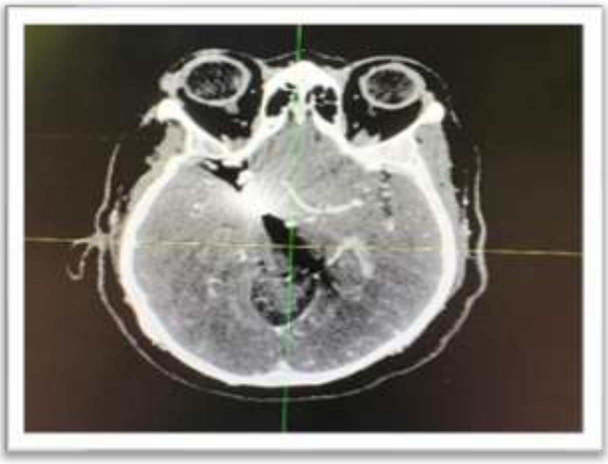


Figure 6 CT Image-Axial View

Case 2

Second case is a case of posterior fossa Tumor , Acoustic schwannoma ,2D DICOM images of MRI are provided to the students and are asked to find the involvement of vessels to the tumor ,and after going through the 2D DICOM images ,14 students selected Right ICA as the main vessel,7 students RT MCA,4 Student selected both ICA and 3 students were confused in RT ICA and MCA, Students were confused and there were different answers.

Figure 7 MRI Images of Axial, Coronal and Sagittal view

Case 3

Case Third involve the Arteriovenous malformation and CT Brain angiography was provided It was asked which vessels are involve in the AVM, After 2D DICOM images assessment , only venous sinuses are involve in the AVM according to the 9 students, ACA and venous sinus are involving according to 8 students, all the main vessels (that is MCA ,ACA and venous sinuses) are involving in the formation of AVM according to 7 students,4 students were pretty sure about involvement of MCA and venous sinuses, Hence, Out of 28 ,only 7 Students correctly interpretated the images.

Figure 8 CT angiography-Sagittal, axial and coronal view

Case 4

It is the case of interventricular hemorrhage, assessment was the involvement of bleed in which ventricle ,CT Brain was provided after viewing 2D DICOM images ,15 students were confused between lateral and third ventricle,10 students thought it is present in all ventricles, one student is sure about lateral ventricle and 2 students were confused between fourth and lateral ventricles, Only few students were correct

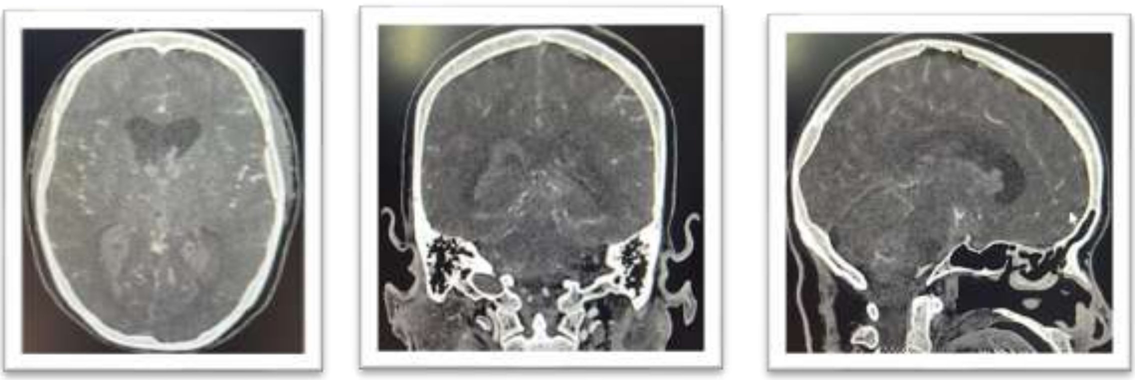


Figure 9Computed Tomography Images-Axial, Coronal and sagittal

CASE 5

Case 5 is related to Tumor at the area just near the lateral ventricle, assessment was the involvement of the tumor with ventricles, Computed tomography images was provided and after going through the 2D DICOM images, 11 students were completely sure about there is no involvement of tumor with the ventricle and according to 9 students there is involvement of tumor, and 8 students were confused and couldn't analyze so there was confusion after 2D DICOM Assessment.

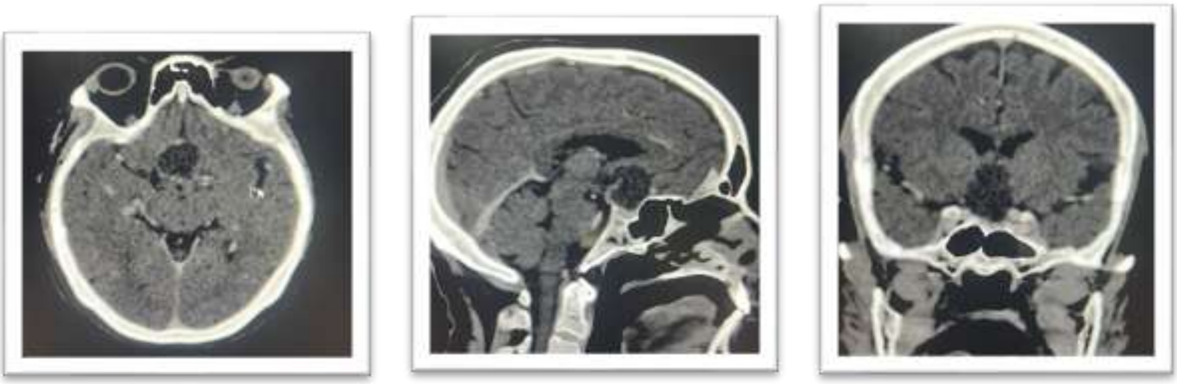
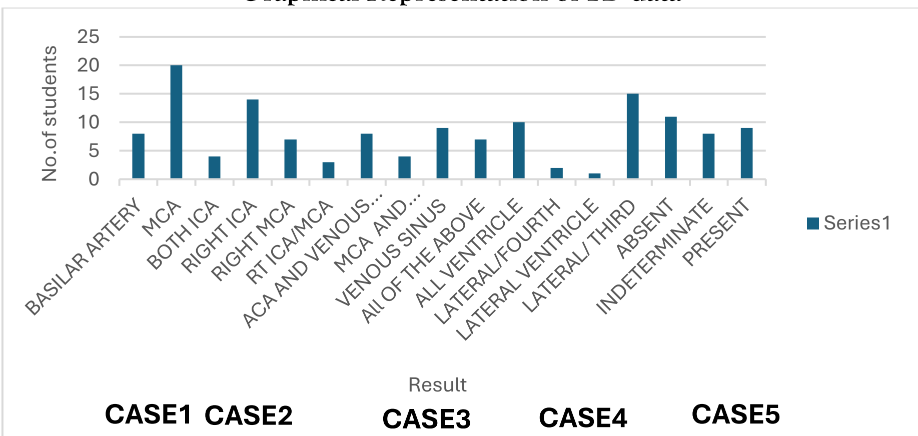


Figure 10Computed Tomography Image-Axial, Sagittal and Coronal

Graphical Representation of 2D data



QUANTITATIVE ANALYSIS OF 3D VIRTUAL REALITY DATA

Students are provided with a Virtual reality headset and allow them to view 3D Anatomy of the same cases with the help of Immersive Education Module, after immersing in the 3D virtual reality environment answers shifted to more accurate and non-confusing

SR.no	No of Case	Response Given by Participants	NO of Response
1	CASE 1	BASILAR ARTERY	6
2		MCA	22
3	CASE 2	BOTH ICA	24
4		RIGHT ICA	4
5	CASE 3	ALL OF THE ABOVE	20
6		VENOUS SINUS	8
7	CASE 4	ALL VENTRICLE	27
8		LATERAL VENTRICLE	1
9	CASE 5	ABSENT	28
10		PRESENT	0

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Case 1

In first case Students are asked to Identify the location of Intracranial Aneurysm present at left middle cerebral artery, after visualization of 3D Model of anatomy with VR HEADSET most of the student are surer and answer shifted ,22 students now chose MCA as base location of aneurysm, which was correct and 6 students selected Basilar artery, it was still unsure for some students,

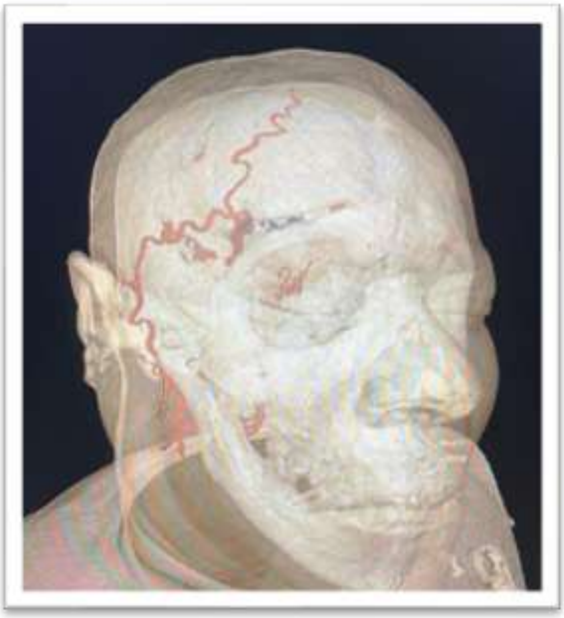

Figure 11 3D model of case1

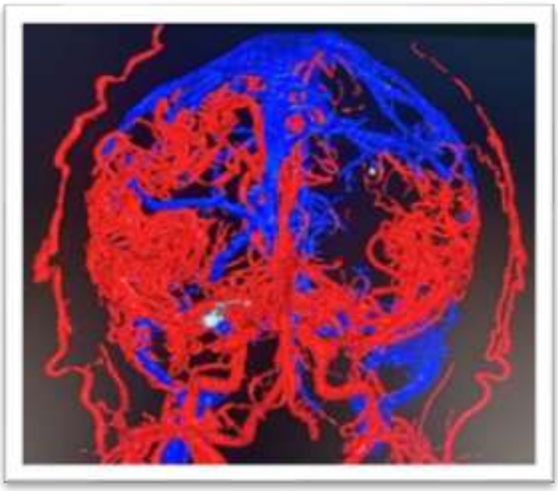

Figure 12 Anterior view

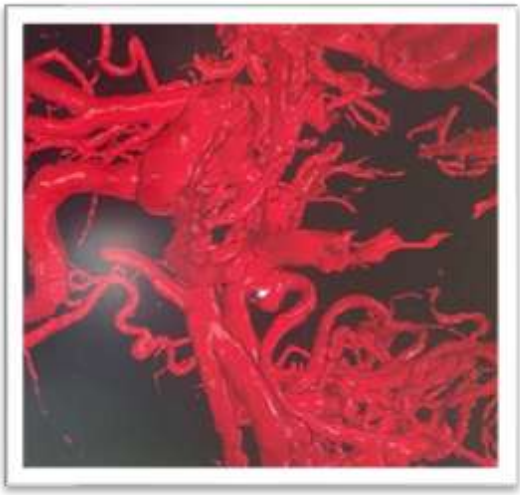

Figure 13 Enlarge view of aneurysm

Case 2

It is the case of posterior fossa Tumor, Acoustic schwannoma ,3D Model are provided to the students using Immersive education module and it is assessed with the help of Virtual reality simulator now after immersing in the Virtual reality environment ,24 Students believing both Internal (Right and left) Carotid artery are involving with the Tumor and according to 4 students only Right Internal carotid artery is involved,

Figure 14 3D Model of case 2

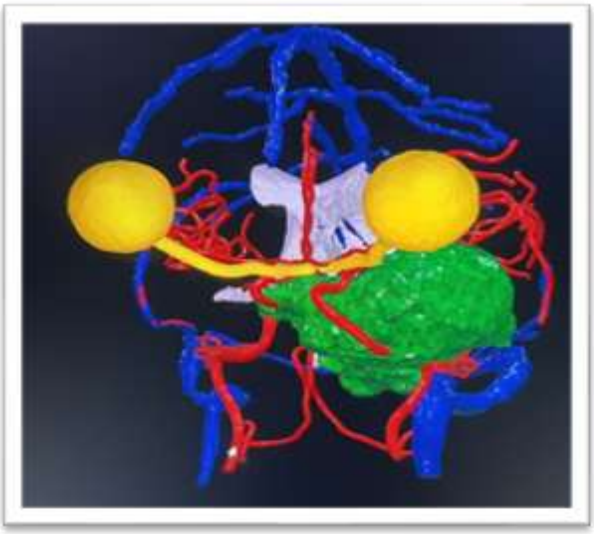

Figure 15 Anterior view

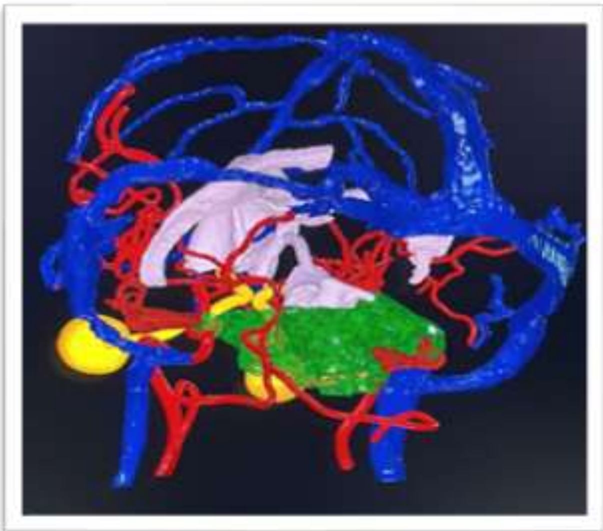

Figure 16 posterior view

Case 3

Case third is the case of Arteriovenous malformation and feeding vessels was asked ,a 3D Model of Bones ,Arteries(Circle of Willis), vein , AVM, optic nerves and skin was provided, after visualization of 3D Model in virtual reality environment students felt more comfortable and confident and 20 Students chose all vessels involvement that is MCA,ACA and venous sinus in the AVM and 8 student chose only venous sinus as the feeding vessel of the AVM

Figure 17 3D Model of case 3

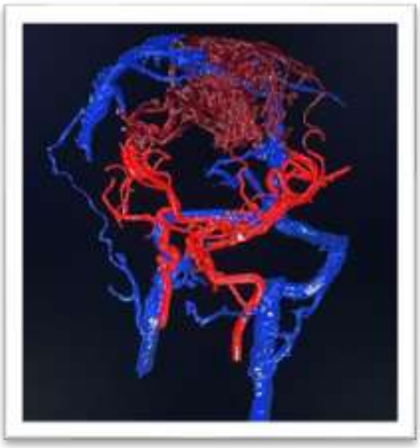

Figure 18 Anterior view

Figure 19 posterior lateral view

Case 4

It's a case of interventricular hemorrhage, it was asking which part of ventricle is affected by hemorrhage, a 3D model of patient was provided to the students and after viewing of 3D model 27 student selected all ventricles including (lateral, third and fourth) and only one student was confused with the anatomy thought it's in the lateral ventricles only

Figure 20 3D model of case 4

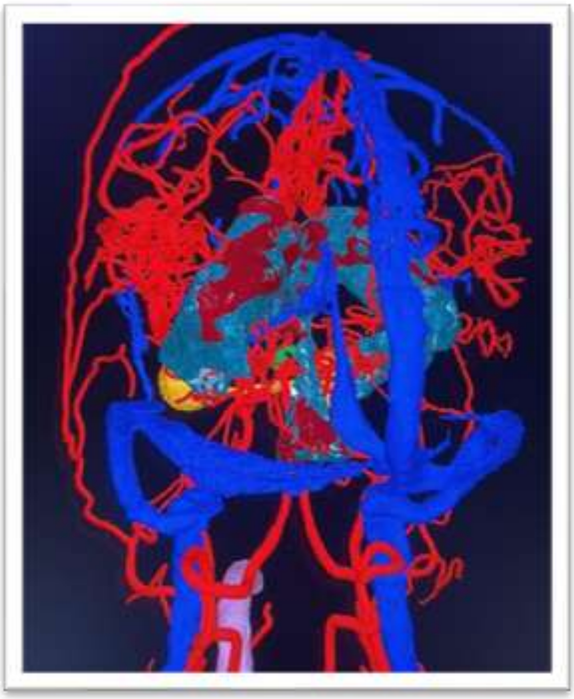

Figure 21 Anterior view

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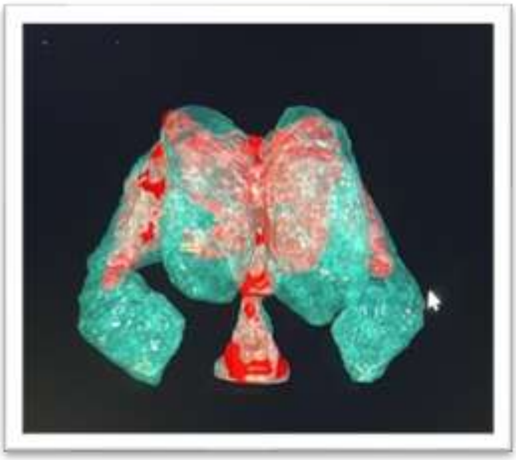

Figure 22 3D model of Ventricles

Case 5

Case 5 is related to Tumor at the Cavernous area just near the ventricles and assessment was the whether Tumor is going to the ventricles or there is no evidence of tumor in the ventricles, a 3D model of Skin ,Bones, Ventricles vessels and optic nerves was provided and after going through the 3D Model of the case out of 28 Students all the student were sure there is no involvement of Tumor in the ventricles, there was no confusion

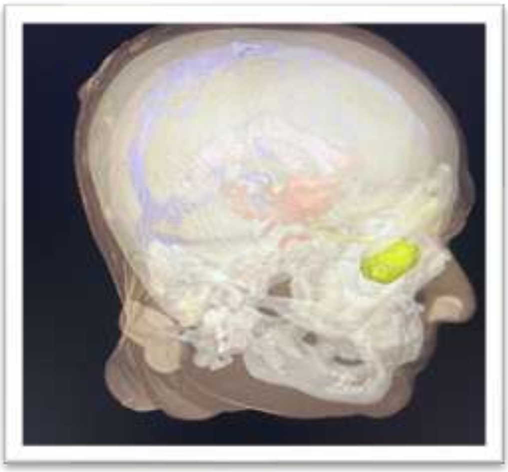

Figure 23 3D Model of case 5

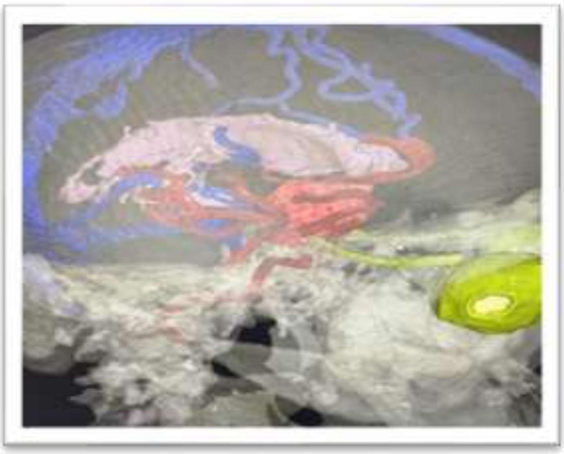

Figure 24 RAO View

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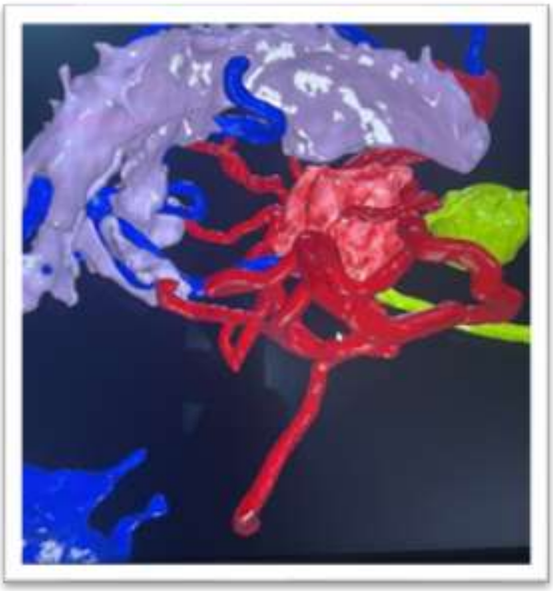
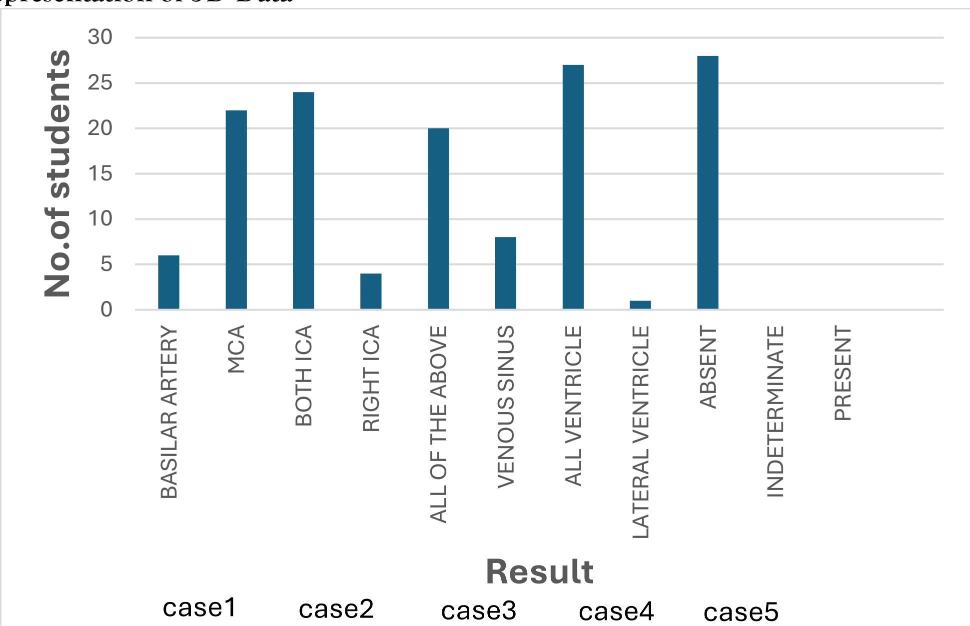


Figure 25 Lateral view

Graphical Representation of 3D Data



COMPARITIVE DATA

In First case, out of 28 students ,8 Students selected basilar artery, and 20 students selected Middle cerebral artery in 2D Assessment and after visualization with VR HEADSET answer shifted and now 22 students are confident in MCA is the location of aneurysm and 6 students selected Basilar artery,

In the second case ,students are asked to find the main vessels involvement to the tumor ,and after going through the 2D DICOM images ,14 students selected Right ICA as the main vessels ,7 students RT MCA,4 Student selected both ICA and 3 students were confused in RT ICA and MCA and after 3D VR model assessments it was clear to 24 students that both ICAs are the main involved vessels to the Tumor ,4 students selected only Right ICA is supplying to the Tumor.

Case Third involve the Arteriovenous malformation and It was asked which vessels are feeding vessels in the AVM, After 2D assessment ,Out of 28 ,only veins are involve in the AVM according to the 9 students, ACA and venous sinus are feeding according to 8 students, all the vessels including ACA,MCA,Venous Sinuses are feeding

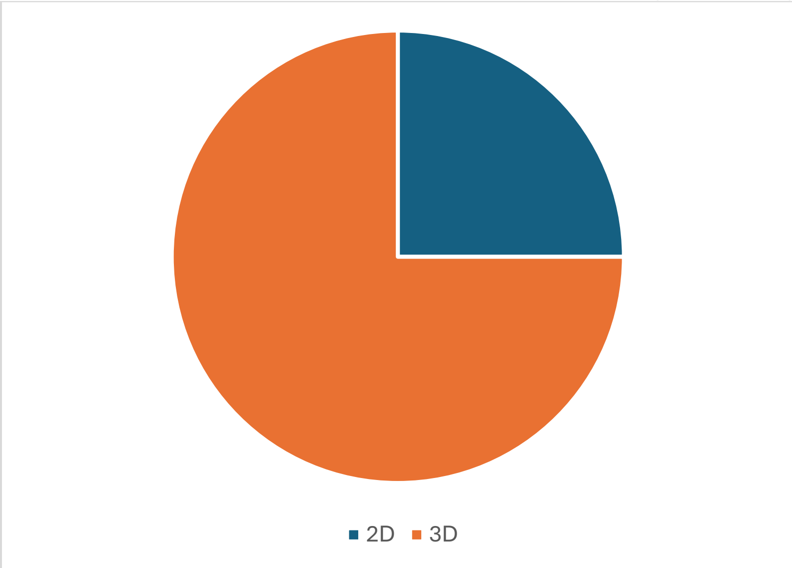
vessels of AVM according to 7 students,4 students were pretty sure that feeding vessels are MCA along with venous sinuses but after the visualization of 3D model with the help of VR Headset these answers were changed and number changes to 20 and 8 ,20 students chose all the vessels involvement and only venous sinus are involving according to 8 students.
Case 4 is the case of interventricular hemorrhage, assessment was the involvement of bleed in which ventricle ,after viewing 2D DICOM images ,15 students were confused between lateral and third ventricle,10 students thought it is present in all ventricles, one student is sure about lateral ventricle and 2 students were confused between fourth and lateral ventricles, these answers were shifted to 27 and 1 ratio ,all 27 students were completely sure about all ventricle and 1 student thought its in lateral ventricle only
Case 5 is related to Tumor at the area just near the ventricles ,assessment was the involvement of the tumor with ventricle, after going through the 2D DICOM images, 11 students were completely sure about there is no involvement of tumor with the ventricle and according to 9 students there is involvement of tumor , and 8 students were confused and couldn't analyze but after 3D visualization ,it was completely clear there was no involvement of tumor in ventricles.

QUALITATIVE ANALYSIS

- A qualitative analysis was carried out using survey responses and open-ended feedback to gain a deeper understanding of the students' learning preferences and perceptions. Participants were asked to rate the utility of 2D DICOM as opposed to interactive 3D VR representations.

Most students obviously favored the 3D VR models. The replies revealed several similar themes, including enhanced spatial knowledge, improved anatomical visualization, and increased learning engagement. Many students said that the immersive 3D experience made it easier for them to comprehend the complex neuroanatomy, which they found difficult to interpret in conventional 2D slices.

- Additionally, participants stated that the 3D models improved their confidence in recognizing and comprehending neurovascular systems and made it easier for them to localize diseases. One significant benefit of the 3D models was their interactive nature, which made it possible to manipulate images and better explore anatomical linkages. The quantitative results are generally well supported by the qualitative comments, which show that students prefer and find 3D VR models more useful for deciphering neuroimaging instances.



DISCUSSION

This study demonstrates the educational efficacy of immersive virtual reality (VR) in radiology training, particularly in enhancing the spatial understanding and diagnostic accuracy of complex neuroanatomical cases. The findings align with previous research, such as Moro et al., observed that VR-based modules improved student engagement and anatomical comprehension significantly more than traditional modalities [16]. Our results corroborate these observations, showing that students performed better and expressed greater clarity when interacting with 3D immersive models following 2D DICOM reviews.

Furthermore, consistent with Nicholson et al., immersive technology fosters deeper learning through interactive visualization and spatial mapping, which are particularly valuable in domains like radiology that demand high-level spatial reasoning [17]. Students in our study perceived the VR-enhanced format as more intuitive, reinforcing Ekstrand et al.'s conclusion that immersive methods can reduce cognitive load while improving retention of spatial information [18]. The clarity and precision offered by VR in visualizing complex vascular structures, such as aneurysms and ventricular involvement, led to more accurate interpretations compared to 2D-only approaches.

Brenton et al. also reported that integrating immersive tools promotes student motivation and autonomy, especially when paired with self-directed learning and clinical scenarios [19]. These findings echo into our student feedback, where immersive tools were preferred for their clarity and perceived realism. Importantly, our study underscores that the immersive experience does not replace traditional learning but complements it, a sentiment shared by Maresky et al., who emphasize that multimodal exposure (2D + 3D) enhances comprehension without sacrificing foundational skills [20].

Nonetheless, limitations exist. The novelty of VR may initially elevate enthusiasm, potentially skewing self-reported preferences, a concern also highlighted by Moro et al. Additionally, the single institution setting and limited sample size constrain the generalizability of our findings. Future studies could benefit from larger multi-center trials, longitudinal tracking of diagnostic proficiency, and the integration of objective assessment tools such as eye-tracking or neurofeedback.

Despite these limitations, our findings contribute meaningfully to the growing body of evidence supporting immersive education in radiology and medical imaging. As technology becomes more accessible, integrating VR modules into mainstream curricula could foster more spatially literate, diagnostically accurate, and engaged imaging professionals. Continued collaboration between educators, radiologists, and software developers will be critical to standardizing immersive learning and aligning it with clinical competencies.

CONCLUSION

The purpose of this study was to compare how well postgraduate radiology students interpreted neuroimaging cases using traditional 2D DICOM pictures against 3D virtual reality (VR) models. It is clear from the outcomes of both objective performance and subjective feedback that the 3D VR models offered a more successful educational experience.

When utilizing 3D models, students answered questions on the neural cases more accurately, and a sizable majority of them indicated that they strongly preferred the 3D approach. According to qualitative comments, their comprehension of intricate anatomical systems, spatial orientation, and level of involvement with the learning process were all greatly boosted by the interactive and immersive aspect of virtual reality.

All things considered, the results lend credence to the use of 3D virtual reality (VR) technology in radiology education as an adjunct to conventional imaging, especially when teaching complex neuroanatomy. This method not only increases understanding but also gives students more self-assurance in their ability to evaluate images.

To further validate the impact of immersive VR learning in clinical radiology education, it is recommended that future studies be conducted with a broader sample size and a variety of case types.

APPENDIX

Assessment of Neurovascular Pathologies Using Conventional 2D Imaging and Immersive 3D VR: A Case-Based Analysis"

Case 1

1. Identify the anatomical location of the aneurysm in this case:
a) Middle Cerebral Artery (MCA)
b) Anterior Communicating Artery
c) Posterior Communicating Artery
d) Basilar Artery

2. Which imaging modality allowed better visualization of the spatial relationship between the aneurysm and adjacent vascular structures?
a) 2D DICOM images
b) 3D Virtual Reality (VR) model
c) No significant difference
d) Difficult to assess in both modalities
Case 2
3. Which vascular structure is involved in relation to the tumor in this case?
a) Left Middle Cerebral Artery (MCA)
b) Right Middle Cerebral Artery (MCA)
c) Left Internal Carotid Artery (ICA)
d) Right Internal Carotid Artery (ICA)
4. Is there evidence of tumor involvement or compression affecting the optic chiasm?
a) Yes
b) No
c) Indeterminate/Not sure
Case 3
5. Which vascular territories are involved in the arteriovenous malformation (AVM) in this case?
a) Anterior Cerebral Artery (ACA)

b) Middle Cerebral Artery (MCA)
c) Venous sinus.
d) Both ACA and MCA
6. Is there evidence of ventricular involvement secondary to
the AVM?
a) Yes
b) No
c) Indeterminate / Not sure

Case 4
7. Based on the provided imaging, identify the location of the intraventricular hemorrhage:
a) Lateral ventricle
b) Third ventricle
c) Fourth ventricle
d) Brainstem
8. Is there evidence of an associated aneurysm in this case?
a) Yes
-b) No
c) Indeterminate / Possibly present
Case 5
9. Is there radiological evidence of intraventricular extension or involvement by the tumor?
a) Present
b) Absent
c) Indeterminate
10. Is there evidence of midline shift or mass effect resulting in displacement of central neuroanatomical structures?
-a) Present
-b) Absent
c) Indeterminate

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