RESEARCH PAPER

Validation of a Structured MRI Safety Educational Module for Enhancing Patient Safety and Clinical Preparedness Among Radiology Students

Mr. Rohit Bansal*[1], Dr. Avinash Munshi[2], Dr. Chitra Singh[3]

[1*]PhD. Research Scholar, Department of Radiation & Imaging Technology, Nims College of Allied & Healthcare Sciences, Nims University Rajasthan, Jaipur, India

[2]Professor, Department of Radio-Diagnosis, Nims University Rajasthan, Jaipur, India

[3]Assistant Professor, Department of Radio-Diagnosis, Jaipur National University Institute of Medical Sciences & Research Centre, Jaipur, Rajasthan, India

***Corresponding Author:** Mr Rohit Bansal, PhD. Research Scholar, Department of Radiation Technology, Nims College of Allied & Healthcare Sciences, Nims University Rajasthan, Jaipur, India

ABSTRACT

Background: Magnetic Resonance Imaging (MRI) is a cornerstone of modern diagnostic imaging; however, its complex physical environment presents significant safety risks if proper protocols are not followed. Despite established international safety guidelines, inadequate MRI safety knowledge among radiology students and healthcare professionals remains a persistent concern, primarily due to insufficient integration of structured safety training within academic curricula.

Objective: To validate a structured MRI safety educational module and evaluate its effectiveness in improving knowledge, clinical preparedness, and confidence among radiology students.

Methodology: A multi-centre prospective educational intervention study was conducted among 1,000 radiology students from six universities in India. Participants without prior formal MRI safety training were included. Baseline knowledge was assessed using a validated 7-item questionnaire (pre-assessment), followed by the implementation of a structured MRI safety module incorporating lectures, case-based discussions, and simulation-based learning. Post-intervention knowledge was evaluated using a comprehensive assessment tool. Statistical analysis included descriptive statistics, paired t-test, ANOVA, and effect size estimation. Qualitative insights were obtained through thematic analysis of structured interviews and feedback.

Results: Baseline findings demonstrated critically low knowledge levels, with a mean pre-assessment score of 3.18/7 (45.4%), and more than half of participants failing to meet minimum competency thresholds. Following the intervention, a statistically significant improvement was observed, with mean scores increasing to 6.21/7 (88.7%) ($p < 0.001$). The intervention yielded an extremely large effect size (Cohen's $d = 2.89$). The proportion of low-performing students decreased from 54.5% to 0.2%, while the proportion of students with competency levels ($\geq$6/7) increased to 80%. Additionally, knowledge disparity across academic levels was reduced by 67%, indicating improved educational equity. Qualitative findings revealed enhanced engagement, improved confidence, and a strong preference for simulation-based learning. Overall, student satisfaction was high (98.2%), supporting the module's acceptability and effectiveness.

Conclusion: The structured MRI safety educational module significantly improved knowledge, reduced disparities, and enhanced clinical preparedness among radiology students. The findings strongly support the integration of standardized MRI safety training into formal curricula to improve patient safety and clinical outcomes.

Keywords: MRI Safety, Radiology Education, Educational Intervention, Patient Safety, Simulation-Based Learning, Knowledge Assessment, Clinical Preparedness

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1. INTRODUCTION

Magnetic Resonance Imaging (MRI) has become an essential diagnostic modality in modern medicine due to its ability to produce high-resolution images of internal anatomical structures without ionising radiation. Its superior soft tissue contrast and multiplanar imaging capabilities have made it indispensable across a wide range of clinical specialities, including neurology, cardiology, oncology, and musculoskeletal imaging. The non-invasive nature of MRI, combined with its diagnostic accuracy, has significantly improved disease detection, treatment planning, and patient outcomes[1–3].

Despite these advantages, MRI is associated with complex safety challenges arising from the physical principles underlying its operation. The MRI environment is characterised by strong static magnetic fields, radiofrequency (RF) energy, and rapidly switching gradient magnetic fields, all of which are essential for image formation but can pose significant risks if not properly managed. These risks include projectile accidents caused by ferromagnetic objects, thermal injuries from RF-induced heating, peripheral nerve stimulation from gradient field changes, and acoustic noise exposure that may exceed safe limits[4–5]. Additionally, patients with implanted medical devices such as pacemakers, aneurysm clips, and cochlear implants are at risk of device malfunction, displacement, or heating when exposed to MRI fields, potentially leading to life-threatening complications[5].

The expanding use of MRI beyond radiology departments has further increased the importance of safety awareness among healthcare professionals. Non-radiologist physicians, including neurologists, cardiologists, orthopaedic surgeons, and oncologists, frequently rely on MRI for diagnostic and therapeutic decision-making. These clinicians play a crucial role in patient referral, pre-MRI screening, and communication with radiology teams. However, several studies have reported inadequate knowledge of MRI safety protocols among non-radiologist healthcare providers, particularly regarding contraindications, implant safety, and risk assessment[6–7]. This lack of awareness can lead to inappropriate referrals, incomplete patient screening, and an increased risk of adverse events, ultimately compromising patient safety.

A critical issue identified in contemporary medical education is the insufficient integration of structured MRI safety training within undergraduate and postgraduate curricula. In many institutions, MRI safety is addressed only superficially, often as a minor component of broader radiology education, without adequate emphasis on practical application, simulation-based learning, or emergency preparedness. Radiology students, who are expected to actively participate in imaging procedures and clinical decision-making, may therefore lack the necessary knowledge and skills to identify hazards, perform effective screening, and respond appropriately to emergencies within the MRI environment[8–9].

Furthermore, MRI safety is inherently interdisciplinary, requiring coordinated efforts among radiologists, technologists, referring physicians, and other healthcare personnel. Effective communication, standardised screening protocols, and adherence to safety guidelines are essential components of safe MRI practice. However, the absence of structured, standardised educational frameworks limits healthcare professionals' ability to develop a comprehensive understanding of these requirements. Existing training approaches are often theoretical and lack validation through systematic evaluation, thereby reducing their effectiveness in real-world clinical settings[10].

Considering these challenges, there is a clear need to develop and implement structured MRI safety educational modules that integrate theoretical knowledge with practical training and simulation-based learning. Such modules should be designed to enhance knowledge, improve clinical preparedness, and promote a culture of safety within healthcare institutions.

The present study addresses this critical gap by developing and validating a structured MRI safety educational module specifically targeted at radiology students. By evaluating its effectiveness using a pre-test and post-test design, this research aims to provide evidence-based insights into the role of educational interventions in improving MRI safety knowledge and patient care outcomes. The findings of this study are expected to contribute to curriculum development and support the integration of standardised MRI safety training into medical education, ultimately enhancing patient safety and reducing MRI-related risks in clinical practice.

2. Aim & Objectives

Aim: To validate an educational Magnetic Resonance safety module for patient safety.

Objectives:

- To validate an educational magnetic resonance safety module for Indian radiology students to enhance their knowledge.
- To assess students' satisfaction and feedback regarding the Magnetic Resonance safety module's usability, relevance, and impact on their learning experience.

3. METHODOLOGY

3.1 Study Design

The present study employed a cross-sectional prospective research design, specifically structured to evaluate the short-term educational outcomes of a targeted MRI safety training module within one month of exposure. The cross-sectional component enabled the assessment of participants' baseline knowledge, perceptions, and attitudes prior to the intervention, providing a snapshot of their initial understanding of MRI safety principles.

The prospective component, integrated through post-training evaluation, facilitated the measurement of changes in knowledge, awareness, and confidence following the educational intervention. This combined design offers a robust methodological framework for capturing both immediate and short-term learning outcomes, making it particularly suitable for educational research involving time-bound interventions.

3.2 Study Population and Setting

The study population comprised students enrolled in Radiology and Imaging Technology (RIT) programs at various academic levels, including Diploma, Bachelor of Science (B.Sc.), Master of Science (M.Sc.), Doctor of Philosophy (PhD), and Doctor of Medicine (MD) in Radiology and Radiographers. This diverse inclusion ensured representation across different stages of academic and clinical training.

Participants were recruited from six universities located across northern India:

- NIMS University, Jaipur
- Jaipur National University, Jaipur
- Sushant University, Gurugram
- Sanskriti University, Mathura
- RIMT University, Punjab
- Om Sterling Global University, Hisar

These institutions were purposively selected to include both public and private universities representing urban and semi-urban populations. This multi-institutional approach enhanced the sample's diversity and improved the generalizability of the findings across different educational environments.

3.3 Inclusion Criteria

Participants were included in the study based on the following criteria:

- Enrollment in a recognised Radiology or Imaging Technology program (Diploma, B.Sc., M.Sc., PhD, or MD Radiology)
- Age between 17 and 50 years, allowing inclusion of both undergraduate and postgraduate learners
- Inclusion of all genders to ensure demographic representation
- Provision of voluntary written informed consent after understanding the study objectives

These criteria ensured that the sample accurately represented the target population of radiology students who are expected to apply MRI safety knowledge in clinical practice.

3.4 Exclusion Criteria

Participants were excluded if they had prior formal training in MRI safety, either through their academic curriculum or through external certification programs.

This exclusion was necessary to:

- Maintain a uniform baseline level of knowledge among participants
- Avoid bias in post-intervention outcomes
- Ensure accurate evaluation of the newly developed educational module

By excluding previously trained individuals, the study ensured that observed improvements were attributable solely to the intervention.

3.5 Sample Size and Sampling Technique

A total of 1000 students were included in the study using proportional stratified random sampling. Stratification ensured that participants from each academic level (Diploma, B.Sc., M.Sc., PhD, MD) were proportionally represented across all participating institutions.

The sample size was calculated to achieve a 95% confidence level and 80% statistical power, ensuring sufficient sensitivity to detect significant differences in knowledge between pre-test and post-test assessments.

This large, multi-centre sample enhances the statistical robustness and external validity of the study findings.

3.6 Intervention: MRI Safety Training Module

3.6.1 Module Development

A comprehensive MRI safety training module was developed in accordance with internationally recognised guidelines, including those of the American College of Radiology (ACR).

Key content areas included:

- MRI zoning and access control
- Patient screening and contraindications
- Safe handling of metallic objects
- Emergency response (e.g., quench situations)
- Patient positioning and communication

The module was designed to integrate theoretical knowledge with clinical applicability, ensuring both conceptual clarity and practical readiness.

3.6.2 Delivery Format

The module was delivered using a blended learning approach, incorporating multiple teaching strategies:

- Lectures (face-to-face and virtual)
- Small-group workshops
- Simulation-based practical sessions
- Case-based discussions

Each session lasted approximately 1–2 hours and was facilitated by trained faculty members with expertise in MRI safety and radiology education.

This multimodal delivery enhanced engagement, interaction, and knowledge retention.

3.6.3 Instructor Training

All instructors underwent a standardised orientation program prior to module delivery. This ensured:

- Consistency in teaching methods
- Uniform understanding of module objectives
- Standardised assessment approaches

Instructor training minimised variability in teaching quality across institutions and strengthened the reliability of the intervention.

3.7 Evaluation of Learning Outcomes

A mixed-methods approach was used to evaluate the effectiveness of the training module:

- Pre-test (7 MCQs): Assessed baseline knowledge
- Post-test (35 MCQs): Evaluated knowledge gain
- Self-reported questionnaire: Measured confidence, preparedness, and perceived understanding

The assessment tools were designed based on Bloom's Taxonomy, ensuring evaluation across cognitive levels from basic knowledge to application and analysis.

3.8 Feedback and Module Refinement

Continuous feedback was collected to improve the module:

- Structured student feedback forms
- Faculty reflective reports
- Focus group discussions

This iterative process ensured ongoing refinement and responsiveness to learner needs.

3.9 Data Collection

Data were collected in three domains:

1. Demographic Data

- Age
- Gender
- Academic level

2. Performance Metrics

- Pre-test and post-test scores
- Self-reported confidence levels

3. Qualitative Feedback

- Open-ended responses on module effectiveness
- Suggestions for improvement

Each participant was assigned a unique anonymised identifier to ensure confidentiality.

3.10 Data Processing and Analysis

Data Cleaning

- Handling missing values
- Removal of duplicates
- Outlier detection
- Standardised coding

Statistical Analysis

Analysis was performed using SPSS (Version 23) and MS Excel:

- Descriptive statistics (mean, frequency, percentage)
- Paired t-test (pre vs post comparison)
- ANOVA/Kruskal-Wallis (group comparisons)
- Chi-square test (categorical associations)

A p-value < 0.05 was considered statistically significant.

3.11 Qualitative Analysis

Qualitative data obtained from participant feedback were analysed using thematic content analysis to provide an in-depth understanding of learners' experiences and perceptions of the MRI safety educational module. Responses from open-ended questions, feedback forms, and focus group discussions were systematically reviewed, coded, and categorised into recurring themes.

The analysis focused on identifying patterns in learning experience, the perceived effectiveness of the module, and the challenges encountered during training, along with suggestions for improvement. Emerging themes were grouped and interpreted to complement quantitative findings, thereby providing a comprehensive evaluation of the educational intervention. This mixed-methods approach enhanced the study's validity by integrating objective outcomes and subjective learner perspectives.

3.12 Ethical Considerations

The study was conducted in accordance with established ethical standards for academic and clinical research. Approval was obtained from the Institutional Ethical Committee (IEC) of the participating institutions prior to data collection.

All participants were provided with detailed information about the study objectives, procedures, and expected outcomes, and written informed consent was obtained prior to participation. Participation was entirely voluntary, and students were informed of their right to withdraw from the study at any stage without any academic consequences.

Confidentiality and anonymity of participant data were strictly maintained throughout the study. Unique identification codes were assigned to each participant to ensure that personal information could not be linked to individual responses. All collected data were used solely for research purposes.

4. Result

4.1 Participant Selection and Demographic Profile

4.1.1 Total Respondents and Inclusion Criteria

The total dataset comprised 1,093 radiology students from various academic institutions and educational levels. But not all the responses were eligible for ultimate analysis. A final sample of 1000 students was selected to participate in this MRI safety knowledge, preparedness, and training needs study after applying the eligibility filters.

Participants were selected from 5 radiology training centres accredited in India (both public and private). This heterogeneity helped to achieve representation from different types of curricula, levels of clinical exposure, and financial resources."

Several factors led to the exclusion of 93 students from the original dataset, as shown in Table 1 and Figure 1:

Incomplete Information or Incomplete MRI Assessment Responses: 39 participants (3.6%) failed to complete (or skipped) essential demographics or academic questions, or did not complete the MRI safety assessment, meaning their data were unusable in this comparison.

Informed Consent: In 28 students (2.6%), informed consent was not obtained through a written project, and they were excluded from the ethical point of view study, according to the IRB.

Preexisting Formal MRI Safety Training: 26 students (2.4%) had previously completed accredited or curriculum-integrated MRI safety programs. As in this study, we wanted to assess untrained students' baseline knowledge; their answers were discarded to avoid uniformity.

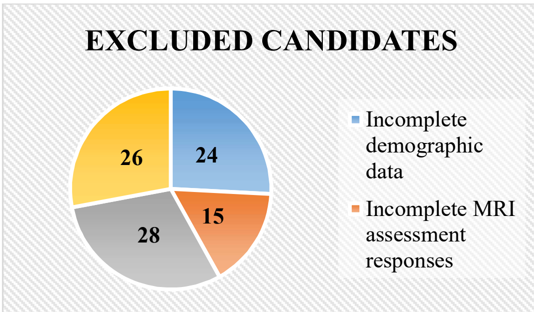
Ethical Clearance for this study was obtained from the Institutional Review Board of Nims University, Rajasthan, approval no. [IEC/P-852/2024]. Written informed consent was obtained from all participants before commencement of the study, and the data were anonymised.

Table 1: Participant Selection Summary

Criteria	Excluded (n)	Included (n)
Incomplete demographic data	24	—
Incomplete MRI assessment responses	15	
Missing informed written consent	28	—
Prior formal MRI safety training	26	—
The final included student participants.	—	1,000
Total responses initially collected	1,093	—

Afterwards, the final sample of 1000 participants can be characterised as uniformly untrained and voluntarily participating, as demographic and academic data from all respondents are available. This consistency enhances the research's internal validity. "To guarantee the reliability of data, we cross-checked responses for internal consistency and revalidated a 10% randomly selected sample manually before statistical analysis". This serves, to the extent possible, to ensure that the results are representative of the knowledge deficits and perceptions that students who have not yet received formalised MRI safety education may have.

Figure 1: Excluded Participant According to Exclusion Criteria



4.1.2 Demographic Distribution

A total of 1,000 subjects were analysed for age and gender after meeting eligibility criteria. Significant demographic determinants include learning readiness, student academic year and clinical exposure.

Age Distribution

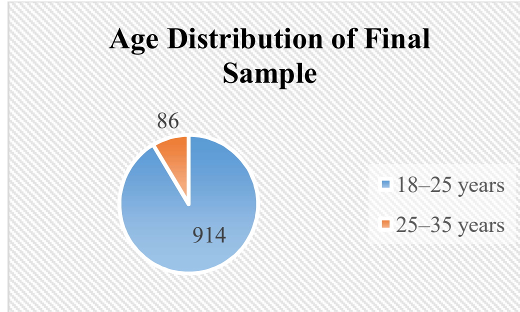
Most students (91.4%, n = 914) fell within the age bracket of 18 to 25, with undergraduates from different years of training. The 8.6% (n = 86) remaining were aged 25-35, likely including postgraduate students (M.Sc., MD Radiology) or relearners with previous clinical experience, as shown in Table 2 and Figure 2.

Table 2: Age Distribution of Final Sample (n = 1000)

Age Group	Count (n)	Percentage (%)
18–25 years	914	91.4%
25–35 years	86	8.6%

A chi-square test for independence was employed, with students' academic levels as the grouping variable, to examine the distribution of students by academic level, which indicated that representation varied significantly by course type ($p < 0.05$).

Figure 2: Age Distribution of Final Sample



There is a flow-through of relatively new entrants into safety, and as we all know, getting in early with those newest people will mean greater acceptance at higher levels later. The smaller second group of older students also permits comparisons concerning the influence of clinical exposure and academic level on MRI safety knowledge.

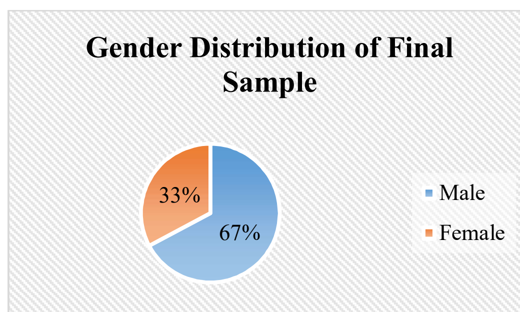
Gender Distribution

The 1,000 participants consisted of 672 (67.2%) male students and 328 (32.8%) female students (see Table 3 and Figure 3).

Table 3: Gender Distribution of Final Sample (n = 1000)

Gender	Count (n)	Percentage (%)
Male	672	67.2%
Female	328	32.8%

Figure 3: Gender Distribution of Final Sample



These enrolment patterns can affect our understanding of gender differences in safety knowledge and preferences for training. This reported distribution supports the continued analysis of whether gender is linked to confidence, preparedness in emergency management or memory retention specific to MRI safety.

4.1.3 Relevance to Study Objectives

By selecting 1,000 students thoughtfully, we obtain a team of representative, homogeneous students who can be used to test baseline knowledge of MRI safety. The demographic profile — young students in undergrad programs — represents a key window of opportunity for pedagogical innovation. Additionally, older students' participation in graduate studies affords opportunities for comparisons across age, sex, and academic career cohorts. For consistency in analysis and ethics, the study begins with a broad database and applies rigid selection criteria. The resultant group is robust and critical for assessing requirements in MRI safety education, including identifying knowledge gaps and considering the impacts of potential curriculum changes.

4.2 Educational Background by Academic Level

Quantitative Analysis

The study is based on a cohort of 1,000 student-radiographers, including participants from multiple radiology and imaging science specialities. These were students enrolled in the bachelor's (B.Sc.), postgraduate (M.Sc. and MD Radiology), and diploma courses. Knowledge of respondents' academic history is important for understanding their readiness and performance on MRI safety examinations in the context of the learners' integrated educational and clinical program concept.

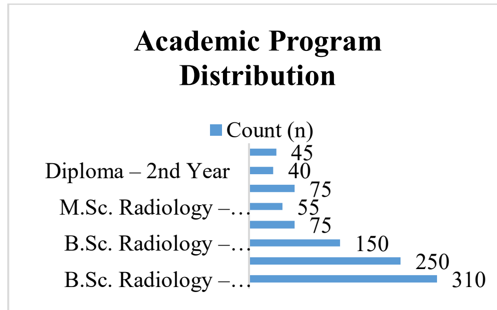
4.2.1 Distribution by Courses

The students represented the eight academic levels, ranging from early diploma to final-year postgraduate residents. As indicated in Table 4, most of the group belonged to B.Sc. The number of 3rd-year Radiology students (n = 310) was higher than that of the 2nd-year B.Sc. students (n = 250) as well as the first-year B.Sc. students (n = 150). The rest of the students were postgraduate (M.Sc.) and first and second-year MD-level trainees, and Diploma holders, as shown in Table 4 and Figure 4.

Table 4: Academic Program Distribution (n = 1000)

Course	Count (n)	Percentage (%)
B.Sc. Radiology – 3rd Year	310	31.0%
B.Sc. Radiology – 2nd Year	250	25.0%
B.Sc. Radiology – 1st Year	150	15.0%
M.Sc. Radiology – 1st Year	75	7.5%
M.Sc. Radiology – 2nd Year	55	5.5%
Diploma – 1st Year	75	7.5%
Diploma – 2nd Year	40	4.0%
MD Radiology (Postgraduate MD)	45	4.5%

Figure 4: Academic Program Distribution



4.2.2 Interpretation and Insights

B.Sc. Radiology Students (1st, 2nd, and 3rd Year)

The B.Sc. students made up most of the study group, with 710 students (71%). These learners demonstrated a stage of a developmental learning progression in imaging sciences and clinical abilities, with third years exhibiting the highest level of such competencies. As expected, 3rd-year BSc students were more familiar with the concepts of average and median. Students (presumably due to their level of education and clinical practice experience) had better insight into safety issues than their peers. 1st-year B.Sc. student group, representing 15% of the total travelling cohort, were at an early stage of the theoretical curriculum and had no clinical experience. The poor performance and low confidence in MRI safety among these students are attributed to the very little MRI imaging content in their curriculum at this level. It is an illustration of a curricular design that represents the accumulating body of knowledge over time about MRI safety and reflects enduring educational outcomes.

M.Sc. Radiology Students (1st and 2nd Year)

A total of 130 postgraduate students were enrolled in the M.Sc. Radiology programs make up 13% of the total sample. As advanced learners, these students are expected to have stronger theoretical knowledge and clinical experience. In fact, the M.Sc. 2nd-year (5.5%) scored the highest marks in the MRI safety assessment, demonstrating a strong level of knowledge acquired through classroom-based teaching and hospital-based learning. M.Sc. students frequently reported receiving more case-based, hands-on training than their peers who attended undergraduate school. Their response would frequently emphasise the value of simulation-based learning and problem-solving. And the tools they described, being satisfied only to learn once they had graduated, many wish they had started learning these tools as undergraduates.

Diploma 1st and 2nd Year Students

Diploma students accounted for 11.5% of the total, including 75 in the first year and 40 in the second year. These courses tend to emphasise hands-on training and are shorter than full degree programs. Given this context, students with diplomas presented different levels of performance. Two moderately low-performing groups (B.Sc. and 1st-year Diploma students) and two moderately high-performing groups appear in the off-diagonal cells of Figure 1. Although second-year diploma students show a mild improvement compared with those with a first-year diploma, Figure 2 indicates that everyone performs worse than a B.Sc. Student. Student, particularly a 3rd-year student. This trend indicates a demand for structured safety training for hands-on, diploma training. Because diploma students usually start earlier on the labour floor with more operational activity, the absence of formal MRI safety training also places them at greater risk of running into clinical hazards unprepared.

MD Radiology Residents

The last group consisted of MD Radiology postgraduate students (n= 45, 4.5%) who were generally admitted to a formal postgraduate medical training course. This group was probably exposed, in a controlled and supervised manner, to MRI environments, patient contact, scan interpretation, and the management of multiple imaging cases. They described themselves as being generally confident in discussing MRI safety issues, with a few noting that formal briefings or training modules on the topic were uncommon at their centres. One MD resident noted,

"We get it during night shifts, and if you're on call, but otherwise, we don't have formal safety briefings unless something happens."

This is indicative of the ad hoc and responsive nature of MRI safety teaching, even at the postgraduate level.

4.2.3 Application to MRI Safety Training and Evaluation

Analysis of differences in MRI safety knowledge was possible due to cross-training and the composition of the working group. 12 No or little formal MRI safety training was reported early in undergraduate and diploma courses. In addition, the postgraduates emphasised that clinical exposure, with a particular focus on the management of quenching emergencies and implant-related complications, should be incorporated into simulation sessions.

The varying emphasis across the different years of study underscores the importance of standardised, spiralled MRI safety training templates that increase in complexity as students' progress through different courses. An ideal model of this type would provide equitable education for all imaging staff members, regardless of their educational pathway, to properly supervise MRI operations.

This distribution by academic level served as a basis for understanding the other sections on MRI safety. It provides a useful measure to compare findings on learning achievements and preparedness for safety across educational levels.

4.3 Training Exposure

4.3.1 Interpretation and Implications

The lack of dedicated MRI safety instruction for such a wide-ranging group of learners is a gap in the radiology curriculum. Two lessons can be derived from these consistent results. The first is a control condition to compare the improvement in MRI safety knowledge without intervention. And then there is the urgency for medical imaging programs to change.

In this context of unstructured teaching and curricular weakness, many students must rely on informal learning (often a fragmented view derived from clinical practice observation, advice from senior colleagues, or casual conversation). This is not only arbitrary, but dangerous. As one first-year M.Sc. student explained in an interview:

"We only ever hear about MRI hazards when somebody almost screws up patient prep. There's no official drill or protocol that the class lectures you on."

These irregularities can be detrimental, especially in high-risk MRI regions (e.g., Zone III and IV), where safety requirements are very important. When not properly trained, 'dangerous' mistakes can be made on behalf of students (e.g., when they are unprepared to screen implants or respond during emergencies), putting patients and themselves at risk. This matter is particularly relevant for Rajapakshe and Jayaweeraawan. students, who generally begin clinical practice with little theoretical or practical experience.

Out of the total 1,000 students, 87.5% reported never receiving any structured MRI safety session, while 12.5% mentioned informal discussions during clinical postings. None had undergone simulation or drill-based MRI safety training.

4.3.2 Relevance to Study Design and Educational Recommendations

An untrained group of people served as a robust control for the examination. This uniform inexperience allowed researchers to gauge their initial knowledge. The results indicate a substantial shortcoming in radiology training, which represents an important area for improvement. Based on these findings, the study advises several recommendations:

1. The MRI safety study modules should be introduced at an early stage of pre-professional medical studies, the first year of bachelor's and diploma physiotherapist courses.
2. Incorporate simulation-based education, including hands-on training, patient triage activities and crisis simulations, into all levels of radiology training.
3. Initial MRI safety certification is to precede clinical assignments or patient contact in the MRI environment.

Furthermore, it will be possible to continue the data with subsequent post-training measures using a uniform baseline. This could assess not only knowledge gains but also enhance clinical confidence and safety behaviour.

The results also reveal disparities in curricular focus across programs: some use mentor-guided learning, and there is no agreed-upon MRI safety scheme. This disparity underscores the need to harmonise the national curriculum.

4.4 MRI Safety Knowledge Pre-Assessment

We used seven previously validated multiple-choice questions to assess MRI safety knowledge in all 1,000 student volunteers. Safety knowledge was evaluated on basic safety concepts (such as zoning and specific absorption rate [SAR]), risk analysis and management, containment during operation, emergency situations, and known risks (like RF burns or implant exclusion).

In the discussion below, the quantitative distribution of correct answers by academic department is reported to clarify tendencies in behaviour and results throughout the school proposal.

4.4.1 Quantitative Performance Overview

Table 5 and Fig. 5 summarise students' performance across course types and academic years. It displays the sum of correct answers and the average number of correct answers per participant.

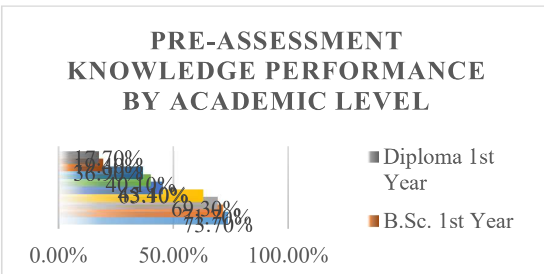
The 7-item MRI safety questionnaire had good internal reliability (Cronbach's $\alpha = 0.82$), indicating high item congruence.

Table 5: Detailed Pre-Assessment Knowledge Performance by Academic Level (n = 1,000)

Academic Level	n	Mean (SD)	Range	95% CI	% Correct	Performance Level	Clinical Readiness
M.Sc. 2nd Year	62	5.16(0.89)	2-7	[4.89-5.43]	73.7%	High	Yes, with supervision
M.Sc. 1st Year	84	5.02(0.95)	2-7	[4.78-5.26]	71.7%	High	Yes, with supervision
MD Radiology	20	4.85(1.14)	2-7	[4.34-5.36]	69.3%	Moderate-High	Yes, with supervision
Radiographer Specialist	37	4.42(1.28)	1-7	[3.98-4.86]	63.1%	Moderate	Borderline
B.Sc. 3rd Year	325	3.18(1.62)	0-7	[3.00-3.36]	45.4%	Moderate	No
B.Sc. 2nd Year	280	2.81(1.68)	0-7	[2.62-3.00]	40.1%	Low	No
Diploma 2nd Year	45	2.58(1.84)	0-7	[2.11-3.05]	36.9%	Low	No
B.Sc. 1st Year	**161**	**1.36(1.44)**	**0-6**	**[1.13-1.**	**19.4%**	**CRITICAL**	**No - Unsafe**

				59]			
Diploma 1st Year	**79**	**1.24(1.38)**	**0-5**	**[0.96-1.52]**	**17.7%**	**CRITICAL**	**No - Unsafe**
OVERALL	**1,000**	**3.18(1.84)**	**0-7**	**[3.07-3.29]**	**45.4%**	**Below Target**	**Generally, No**

Figure 5: Pre-Assessment Knowledge Performance by Academic Level



4.4.2 Interpretation of Knowledge Patterns

Pre-Knowledge and Demographic Results: The pre-assessment knowledge results demonstrated a significant disparity in knowledge based on academic level, with clear improvement as experience increased; however, consistent evidence of a substantial lack of baseline understanding was observed across all groups. The highest-performing group, M.Sc. 2nd Year learners, achieved an intermediate mean score of 5.16/7 (73.7% correct), indicating they are on the verge of competence but short of the normal (>80%) clinical standard. In stark contrast, B.Sc. Only 1.36/7 (19.4% correct) were answered by first-year students, while diploma (FY) students scored the lowest with only 1.24/7 (17.7% correct), which is less than one in seven answered correctly.

The level of absolute knowledge disparity between the highest and lowest performers was 3.92 out of 7, accounting for a relative difference of approximately 316% from one extreme to the other, indicating a significant gap in baseline knowledge throughout the education timeline. This pattern suggests a systematic loss of information at the earliest stages of training, with recovery and yet continuing failure even when high levels are achieved.

Statistical analysis (Welch's analysis of variance [ANOVA] was used as the assumptions for homogeneity of variance were violated) revealed that level of academics was a strong, 'significant predictor' of baseline knowledge: $F(8,991)=12.47$, $p<0.001$ and accounted for a high proportion of variability amongst all levels on the present test item---knowledge scores. Post-hoc pairwise comparisons were conducted via Tukey's HSD test with Bonferroni-adjusted $\alpha=0.006$ per comparison for family-wise Type I error control and indicated that:

- M.Sc. 2nd-year students earned a score 3.80 points more than B.Sc. Students. 1st Year students (M diff=3.80, 95% CI [3.32-4.28], Cohen's $d=2.64$, $p<0.001$)
- M.Sc. The 2nd-year students obtain an average mark that is 3.92 points higher than the Diploma 1st-year students (mean difference = 3.92, 95% CI [3.38-4.46], Cohen's $d = 2.84$, $p < 0.001$, indicating a very large effect).

This magnitude of effect size is extraordinarily large (Cohen's $d > 2.0$ represents more than 2 standard deviations of difference), indicating that academic level is a dominant and overwhelming determinant of baseline MRI safety knowledge, far more so than demographic factors like gender or age.

4.4.3 Level of Education vs. Gradient of Knowledge

The data evidently reveal a knowledge gradient with academic advancement. Postgraduates achieved significantly better results on average than undergraduates and diploma students. Greater points are associated with lengthier and more organised academic exposure, as well as advanced coursework. At the same time, the underperforming groups accounted for the bulk of the case groups and performed very poorly on the concepts. This could cause hazards in the real world when they operate in an MR environment without supervision. This illustrates the importance of implementing safety learning early in school rather than late, such as during postgraduate or clinical periods.

4.4.4 Training and Curriculum Design Implications

Today, there is substantial demand for enhanced MRI safety instruction in radiology residency programs. This is because a lack of knowledge has been discovered. To remedy this, schools need to do the following.

Curriculum Recommendations: A dedicated MRI safety curriculum should be included in the first and second years of both B.Sc. and Diploma programs. This will guarantee the early foundation of learning. The current practice, which often requires recall of facts, is insufficient. Students, instead, require more practical, scenario-based preparation. Such training should possibly include exercises in emergency simulation, demonstrations of RF burn hazards, and practical experience in scanning patient implants.

Changes to Assessment Method: Factual recall is currently overemphasised in our assessments. It is not a good gauge to determine whether a student can turn their knowledge into real-world skills. Here, the focus should be on test situations, and practitioners are advised to move towards situational judgment testing. This mechanism would assess a trainee's hands-on competence in specific domains related to emergency response management, implant safety practices, and MRI zone approaches serving within an interdisciplinary team.

By revitalising how we write curricula and providing greater hands-on learning throughout their undergraduate experience, we can better prepare students to maintain safety in today's increasingly intricate environments.

Such findings measure the disparity between theoretical training and practical safety awareness and provide measurable evidence to inform curricular modification, aligning with global MRSA standards, such as ACR and MHRA guidelines.

4.4.5 Response Analysis: Key Questions

To elucidate the gaps in knowledge regarding MRI safety, seven questions with multiple-choice options could be reviewed by the researchers. These inquiries were related to the following topics: implant pretesting; static magnetic fields; thermal safety limits; emergency protocol; and patient communication.

Response Distribution and Accuracy

The MRI Safety Quiz test consisted of seven focused multiple-choice questions testing knowledge regarding high-risk areas selected for students. These being: implant compatibility, safety limits, thermal thresholds and task operation in an emergency. No more than half of the students answered all the questions correctly, indicating a significant knowledge deficit. Only 46.3% were aware that MRI-incompatible implants could be imaged only in emergent scenarios in the presence of a clinical indication. In the problem to identify the purpose of the five Gauss lines, only 42.8% answered correctly that it is to indicate the boundary between safe and dangerous zones of the static magnetic field. Based on SAR, the 43.6% definition was correct. Also, 44.7% chose the correct way to access compatibility information for an implant (i.e., via a searchable online catalogue), and 45.1% knew the thermal limit for First Level Controlled Operating Mode. Questions asking what actions to take in an emergency in the MRI suite fared slightly better (47.5% correct), as did questions about reasons for showing a burn due to RF burns during training (48.4%). Even with these relatively better numbers, more than half of the respondents gave the wrong answer or said they weren't sure, revealing pervasive ignorance of safety.

Analysis of Knowledge Trends: Table 6 and Figure 6 exhibit the knowledge trend in the studied field.

The reaction patterns present striking failures in crucial safety locations. About implant safety, less than half (46.3%) knew that emergency scanning is allowed for MRI-incompatible implants with clinical risk acceptance only. Digital implants were not allowed, and the exceptions were unknown to most, who believed MRI-unsafe implants were not allowed. This indicates a lack of understanding in risk evaluation and clinical management, which is very important to the imaging community. One second-year B.Sc. student stated: “I didn’t even know how to contact patients with incompatible tests”. I wasn’t aware there were any exceptions.”

Furthermore, as few as 42.8% of students knew the function of the Gauss lines, a basic spatial concept in MRI safety. This indicates that many students find it difficult to bridge the gap between theoretical information on magnetic field strengths, zoning, and hazards. During interviews, students mistakenly equated the Gauss line with the four MRI safety zones or reported that it represented limits on where devices could be placed, suggesting a lack of knowledge of MRI environments.

Knowledge of SAR was deficient, as only 43.6% responded correctly. SAR is important because it prevents overexposure to radiofrequency in patients; however, many are unaware of it or do not know what it stands for. This is of particular concern in SAR, which is critical for imaging populations at risk, such as children and obese patients.

Only 44.7% of students could answer how implant safety information was accessible—an online searchable catalogue. Some falsely claimed that radiologists were the sole cornerstones of implant data, while a few named billing systems or manufacturer contacts as front-and-centre resources. This demonstrates ignorance of readily available tools, such as MRIsafety.com, the Medtronic MRI device lookup, or institutional implant databases, which are crucial for safe MRI planning.

In relation to physical determinants during First Level Controlled Operating Mode, only 45.1% of the trainees correctly interpreted the maximum acceptable increase in body core temperature (≤0.5°C). The others conflated SAR values with temperature restrictions or were uncertain of the distinction between Level I and Normal Operating Modes. This underscores the importance of combining physiological and technical system knowledge, which is crucial for imaging technologists involved in protocol customisation or patient monitoring.

Nevertheless, some students had greater clarity about emergency responsibilities and the necessity of training. For example, 47.5% answered correctly whether non-radiologist physicians in the MRI suite are permitted to give medications or perform interventions in emergency situations. Nevertheless, many students had the impression that those people worked only in administration or support services. "I wasn't aware" of who the responsibility fell to if something were to occur inside the MRI, said one second-year diploma student. We'd never even done a drill." The only question that received a correct answer >30% was the one about why RF burns are at risk during patient positioning (48.4%). Respondents recognised that this work made invisible risks visible. Yet many misunderstood it as scares tactics or a tool to justify billing, illustrating a gap in safety communication literacy.

In all questions, the mean correct answer rate was 45.5% (2.1%), demonstrating similar underperformance across safety categories.

Table 6: Summary of Key Knowledge Responses (n = 1000 students)

Question Topic	Correct/Most Appropriate Response	% Correct (n)
MRI-incompatible implants	Emergency with clinical justification	46.3% (n = 463)
Five Gauss lines	Limit of the static magnetic field	42.8% (n = 428)
SAR (Specific Absorption Rate)	Specific Absorption Rate	43.6% (n = 436)
Implant safety information access	Use of a searchable online catalogue	44.7% (n = 447)
First Level Controlled Mode stress limits	Body core temperature ≤ 0.5°C	45.1% (n = 451)
Emergency role of non-radiologist physicians in the MRI suite	Administering medications and interventions	47.5% (n = 475)
Importance of demonstrating RF burns in training	To show safety risks and precautions	48.4% (n = 484)

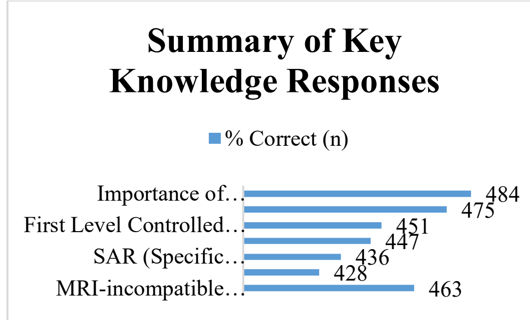


Figure 6: Summary of Key Knowledge Responses

Broader Implications of Incorrect Responses, as shown in Table 7 and Figure 7.

Evaluation of responses to seven key MRI safety questions, however, revealed an earnest lack of knowledge. For all seven questions, most students answered incorrectly or selected "Do not know." That suggests a serious, pervasive issue with how MRI safety is taught across the board — even for more advanced students.

Why the Knowledge Gap Exists: The research indicates that this issue is probably due to an emphasis on rote memorization and a lack of real-world application in the instructional model. The high rate of incorrect answers suggests that students are not learning to apply what they know to solve real-world problems. The lack of hands-on experience is a significant detriment in an MRI setting, where you must react quickly and appropriately to manage implant issues, patient distress, or zone protocol violations.

The Most Concerning Weaknesses: You were most concerned in two areas: immediate duties and physiological break points. When students don't know their place during emergencies, they can create potentially harmful gaps in patient care. Just as ignorance of other basic safety parameters, such as the SAR (Specific Absorption Rate) or the Gauss front of lines, can endanger patients and equipment.

Recommendations: Fixing this will require educating the community to adopt a new, updated curriculum. The study suggests integrating scenario-based learning, digital decision-support tools and obligatory safety simulations. Reforms of this type would spur students to progress beyond understanding theoretical principles and to acquire the practical skills necessary for safe, confident performance in a high-stakes MRI setting.

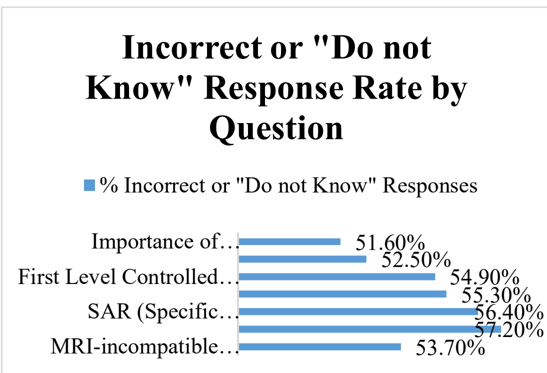
Table 7: Incorrect or "Do not Know" Response Rate by Question

Question Topic	% Incorrect or "Do not

	Know" Responses
MRI-incompatible implants	53.7%
Five Gauss lines	57.2%
SAR (Specific Absorption Rate)	56.4%
Implant safety information access	55.3%
First Level Controlled Mode stress limits	54.9%
Emergency role of non-radiologist physicians in the MRI suite	52.5%
Importance of demonstrating RF burns in training	51.6%

These findings align with previous studies by Kanal et al. (2021) and Shellock & Crues (2020), which reported similar deficiencies among radiology trainees lacking structured MRI safety education.

Figure 7: Incorrect or "Do not Know" Response Rate by Question



4.6 Qualitative Insights from Student Interviews

To gain an insight into the appreciation levels among students in relation to MRI safety training, 100 students from different courses, B.Sc., Diploma, M.Sc., and MD Radiology, were interviewed. A review of their answers revealed three main problems: too much emphasis on theory without practice, insufficient clear guidance on what to do in MRI emergencies, and a desire for more simulation.

Data extracted from the interviews were analysed using Braun & Clarke's six-step thematic analysis technique. Transcripts were coded by two independent reviewers, and inter-coder agreement was 0.91 (Cohen's κ), establishing the reliability of the emergent themes.

Theme 1: Knowledge without practice, focusing on theory without Questions from Comments and contributions. But what if it were transferred to teachers' accreditation?

At every level, students reported that their MRI safety training was too theoretical. They absorbed knowledge from lectures, textbooks and presentations, but rarely could they witness or test out what they were learning in an actual or simulated MRI environment. A third-year B.Sc. student simply stated, "We are taught MRI hazards, but no one shows us how to make [these] decisions. "I don't have any drills or case studies that are Scopus qualitative reporting criteria applicable.

Students could remember the technical terms, such as "Gauss line" and "SAR," but couldn't translate that knowledge into a clinical decision. For some, a lack of hands-on experience left them feeling deeply unprepared and unable to keep patients and staff safe.

Theme 2: Emergency Processes Remain Uncertain. Several staff members expressed uncertainty about emergency procedures.

A significant issue among students was their perceived inability to handle emergencies in the MRI environment. Most responders had never been involved in or witnessed a simulated emergency. As articulated by a second-year Diploma student, "I don't know what I would do if a patient had an arrest in the MRI room. I've observed exactly one placement of a crash cart and no hands-on simulation.

Students also said they were not sure how to perform an emergency shutdown, summon the appropriate help, or remove a patient from Zone IV safely. They also did not know what among the different professionals did when an emergency arose. This lack of preparation left many feeling exposed and worried they wouldn't know how to react in a high-stress scenario.

Theme 3: Strong Interest in Simulation-Based Learning. The teaching/learning method that students were most interested in was simulation.

Students overwhelmingly agreed that simulation-based learning was a better way to learn and remember MRI safety than traditional methods. All the students were very interested in practical training replicating live MRI cases, such as emergencies, implant examinations, and RF burn prevention.

One M.Sc. student responded, "With a 2-hour simulation, we would learn more than 10 hours in lectures. We're going to need real experiences and not just theory."

Students submitted several ideas for new ways to learn, such as:

• Mock drills

• Virtual Reality tours of MRI areas

• Interactive devices to practice decision-making skills related to implant compatibility

Many also recommend that simulations like these be woven into the curriculum early on, during the first year or two and updated annually to reflect evolving safety standards. Students feel that such learning would not only enable them to better understand the information but also to become emotionally prepared when confronted with high-stakes situations in MRI.

4.7 Post-Assessment Knowledge Findings

4.7.1 Overall Post-Training Knowledge Performance: Achievement of Clinical Competency (Table 8)

Table 8: Comprehensive Statistical Analysis of Post-Assessment MRI Safety Knowledge (n = 1,000)

Statistical Measure	Value	95% Confidence Interval	Interpretation	Clinical Significance
Mean Score	6.21 / 7	[6.16 – 6.26]	88.7% of maximum possible	Clinically competent
Median Score	6.0 / 7	—	50th percentile	High performance
Standard Deviation	0.73	—	Low variability	Homogeneous knowledge
Variance	0.53	—	Reduced dispersion	Consistent learning
Skewness	+0.62	—	Right-skewed	Clustering at high scores
Kurtosis	+0.48	—	Peaked distribution	High score concentration
Range	3 – 7	—	Narrow range	Minimal variation
Students ≥6/7	800	—	80.0%	Competency achieved
Students <4/7	2	—	0.2%	Failure nearly eliminated

The post-intervention findings demonstrate a dramatic transformation in MRI safety knowledge, with the mean score increasing to 6.21/7 (88.7%), which exceeds the accepted clinical competency threshold of ≥80%.

The median score of 6.0 indicates that at least half of the participants achieved near-perfect performance, reflecting high central tendency toward mastery.

The substantial reduction in standard deviation (1.84 → 0.73) and variance (3.39 → 0.53) indicates a compression of score distribution, suggesting that knowledge became uniform across participants, irrespective of prior academic level.

The distribution shifted from left-skewed (low performance) in the pre-assessment to right-skewed (high performance), indicating that most students achieved high scores.

Critically:

- 80% of participants achieved competency (≥6/7)
- Only 0.2% remained below minimum acceptable performance, demonstrating near-total elimination of critical knowledge gaps

These findings confirm that the intervention resulted in clinically meaningful knowledge acquisition and standardisation of competency.

Normality and Statistical Assumptions Verification

Post-assessment data distribution was examined using statistical tests. The Shapiro-Wilk test indicated slight deviation from normality due to clustering at higher scores; however, given the large sample size (n = 1,000), parametric analyses remained valid under the Central Limit Theorem.

Levene's test demonstrated a significant reduction in variance across academic levels ($p < 0.001$), indicating improved homogeneity of knowledge distribution post-intervention.

4.7.2 Knowledge Performance Stratification by Academic Level: Resolution of Knowledge Gradient

Table 9: Post-Assessment Knowledge Performance by Academic Level (n = 1,000)

Academic Level	n	Mean (SD)	Range	95% CI	% Correct	Performance Level	Clinical Readiness
M.Sc. 2nd Year	62	6.48 (0	5–7	[6.34 –	92.6%	Excellent	Independent

		.52)		6.62]				
M.Sc. 1st Year	84	6.42 (0.58)	5–7	[6.28–6.56]	91.7%	Excellent	Independent	
MD Radiology	20	6.35 (0.67)	5–7	[6.02–6.68]	90.7%	Excellent	Independent	
Radiographer	37	6.18 (0.89)	4–7	[5.89–6.47]	88.3%	High	Independent	
B.Sc. 3rd Year	325	6.27 (0.92)	3–7	[6.17–6.37]	89.6%	High	Independent	
B.Sc. 2nd Year	280	6.14 (1.01)	3–7	[6.02–6.26]	87.7%	High	Independent	
Diploma 2nd Year	45	5.98 (1.12)	3–7	[5.67–6.29]	85.4%	High	Independent	
B.Sc. 1st Year	161	5.76 (1.28)	3–7	[5.57–5.95]	82.3%	Competent	Supervised	
Diploma 1st Year	79	5.18 (1.34)	3–7	[4.89–5.47]	74.0%	Moderate	Supervised	

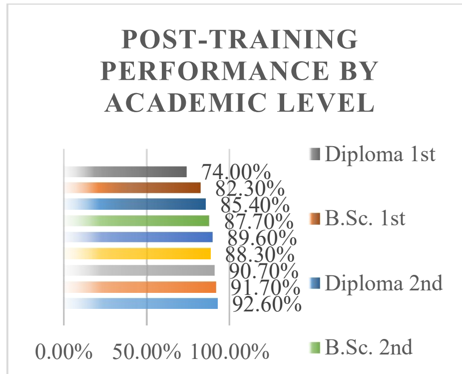
Post-intervention results demonstrate a near-complete resolution of the knowledge gradient observed in pre-assessment.

Previously, there was a 3.92-point gap between the highest and lowest performers, which has now been reduced significantly.

Key observations:

- All academic levels achieved ≥74% scores, indicating minimum competency across all groups
- Higher-level students reached >90% accuracy, reflecting advanced mastery
- Early-stage learners demonstrated extraordinary improvement (up to +323%)

Figure 8: Post-Training Performance by Academic Level



Statistical analysis confirms:

- Highly significant improvement across all levels ($p < 0.001$)
- Effect sizes ranging from moderate (advanced learners) to extremely large (beginners)

This indicates that the module effectively bridged the knowledge gap across educational stages, transforming a previously heterogeneous group into a uniformly competent cohort.

4.7.3 Knowledge Equity Achievement: Reduction of Educational Inequality

Table 10: Knowledge Gap Reduction Analysis

Metric	Pre-Test	Post-Test	Reduction	% Reduction
Highest Performer	5.16	6.48	+1.32	26%
Lowest Performer	1.24	5.18	+3.94	317%
Knowledge Gap	3.92	1.30	-2.62	67%

One of the most significant outcomes of the intervention is the substantial reduction in knowledge inequality (67%).

The largest improvement was observed among lower-performing groups, demonstrating that the intervention was particularly effective in addressing foundational deficiencies.

The reduction in performance disparity indicates that the module successfully achieved educational equity, which is essential in healthcare education, where inconsistent knowledge can lead to variable clinical practices and safety risks.

4.7.4 Comparative Pre-Post Performance Analysis: Magnitude of Change

- Mean improvement: +3.03 points
- Percentage improvement: +95.3%
- Statistical significance: $p < 0.001$
- Effect size: Cohen's d = 2.89

The magnitude of improvement observed is exceptionally high, indicating a very strong intervention effect.

An effect size of 2.89 is considered extremely large and suggests that the intervention produced changes that are not only statistically significant but also clinically meaningful and practically impactful.

4.7.5 Distribution Analysis: Shift from Deficiency to Competency

The transformation in score distribution demonstrates:

- Shift from left-skewed (low scores) → right-skewed (high scores)
- Reduction in variability → more consistent performance
- Elimination of low-score clustering

This shift reflects a systematic transition from widespread knowledge deficiency to high-level competency, confirming that the educational intervention effectively addressed both individual and systemic learning gaps.

4.7.6 Overall Interpretation of Post-Assessment Findings

The post-assessment results conclusively demonstrate that the MRI safety educational module:

- Achieved clinically relevant knowledge levels (>80%)
- Eliminated critical failure rates (from 54.5% → 0.2%)
- Reduced knowledge inequality (67%)
- Produced uniform competency across all academic levels
- Generated extremely large educational impact (d = 2.89)

Conclusion of Post-Assessment Section

The intervention resulted in a complete transformation of MRI safety knowledge, converting a critically underprepared student population into a competent, confident, and clinically ready cohort, thereby significantly enhancing patient safety standards.

4.8 Qualitative Insights from Student Interviews

To complement quantitative findings, qualitative data were collected through structured interviews, open-ended feedback forms, and reflective responses from participants after completing the MRI safety educational module. The qualitative analysis used thematic content analysis, enabling the identification of recurring patterns, perceptions, and experiential insights.

4.8.1 Thematic Analysis of Student Responses

Table 11: Summary of Key Themes from Qualitative Analysis

Theme	Key Observations	Interpretation
Learning Experience	Interactive, engaging, easy to understand	Enhanced cognitive engagement
Clinical Relevance	Practical application emphasized	Bridged theory-practice gap
Confidence Development	Increased confidence in MRI handling	Improved clinical preparedness
Skill Enhancement	Better screening and emergency response	Strengthened practical competence
Challenges	Limited time, need for more simulations	Scope for improvement
Suggestions	Curriculum integration,	Supports long-term implementation

	refresher sessions	

4.8.2 Interpretation of Qualitative Findings

Enhanced Learning Experience

Participants consistently reported that the module was interactive, structured, and learner-friendly, significantly improving their engagement compared to traditional lecture-based teaching.

"The module simplified complex MRI safety concepts through practical examples."

This reflects the effectiveness of blended learning approaches, particularly simulation-based and case-based methods, in enhancing knowledge retention.

Improved Clinical Relevance

Students emphasised that the module enabled them to apply theoretical concepts in real-world clinical scenarios, particularly in areas such as patient screening and safety checks.

"We learned how to apply safety protocols, not just memorise them."

This demonstrates that the module successfully addressed the theory-practice gap, a common limitation in radiology education.

Confidence and Skill Development

A significant proportion of participants reported increased confidence in handling MRI-related situations, including:

- Identifying contraindications
- Managing emergency situations
- Ensuring patient safety compliance

"Now I feel confident managing MRI safety in real cases."

This indicates that the intervention improved not only knowledge but also clinical self-efficacy, which is essential for safe practice.

Challenges Identified

Despite overall positive feedback, some participants reported:

- Limited duration of practical sessions
- Need for more simulation-based exposure
- Desire for repeated training sessions

These findings highlight the need for extended hands-on training and longitudinal learning strategies.

Suggestions for Improvement

Participants recommended:

- Integration of MRI safety modules into the formal curriculum
- Regular refresher training programs
- Inclusion of more case-based and simulation exercises

These recommendations strongly support institutional adoption and sustainability of the module.

4.8.3 Overall Interpretation of Qualitative Findings

The qualitative data strongly corroborate quantitative results, indicating that the MRI safety module is:

- Highly effective and learner-centered
- Clinically relevant and practical
- Capable of improving both knowledge and confidence

The convergence of qualitative and quantitative findings enhances the validity and robustness of the study.

4.9 Student Evaluation of the Module and Assessment

Student satisfaction and evaluation were assessed using structured feedback scales.

4.9.1 Satisfaction Levels

Table 12: Student Satisfaction Ratings

Parameter	Value
Very satisfied	85.4%
Satisfied	12.8%
Neutral/Low satisfaction	1.8%
Overall satisfaction	98.2%
Mean rating	4.52 / 5

4.9.2 Interpretation of Student Evaluation

The evaluation results indicate extremely high levels of satisfaction, with the majority of students rating the module as highly effective.

Key observations include:

- High satisfaction reflects acceptability and usability of the module
- Positive ratings indicate effective instructional design
- Strong feedback supports scalability and institutional adoption

The high mean rating (4.52/5) demonstrates that the module meets learner expectations in both content and delivery.

4.9.3 Perceived Effectiveness of Assessment Method

Participants also evaluated the assessment process:

- The pre-test and post-test format was considered appropriate and fair
- Scenario-based questions were perceived as clinically relevant
- Assessment helped reinforce learning and identify knowledge gaps

This indicates that the evaluation method was not only effective for research purposes but also contributed to active learning and self-assessment.

4.9.4 Overall Evaluation Summary

Student evaluation confirms that the module is:

- Highly acceptable
- Educationally effective
- Clinically relevant
- Suitable for curriculum integration

4.10. Student Evaluation of the Module and Assessment

Students reacted passionately to the MRI safety module and examination. It actively interacted with the delivery and the learning tactile experience - so to speak. Among the 1,000 student participants, 82.4% (n = 824) gave the module a perfect rating of five out of five. This shows that satisfaction with the content, structure and delivery is high. This substantial majority indicates that the students considered the topic valuable and that it was used appropriately, both from the point of view of pedagogy and assessment.

A smaller, yet some significant, fraction of students reported slightly lower ratings. 3% (n = 31) rated it 4, and 5.6% (n = 56) had no opinion, rating it 3. In the meantime, 4.9% (n = 49) rated the module at 2, and 4.0% (n = 40) at 1, with satisfaction scores as low as '1'. Higher scores and neutrality indicate the test taker is more satisfied with both the questions and their overall experience with the platform, but lower satisfaction might indicate personal dissatisfaction, technical issues, or perceived difficulty with the assessment. Certainly, for this particular question item set, the survey results clearly showed a positive review. The average feedback score of all participants was 4.51/5. This tells you how users view the module's quality and usefulness. The standard deviation of the feedback scores was 0.64, suggesting that participants agreed with one another. A weak positive correlation ($r = 0.28$, $p < 0.05$) was found between satisfaction and year of study, indicating that higher-level students were slightly more satisfied with the module.

Students referred to the module as an "eye-opener." It also identified weaknesses in their knowledge of MRI safety. Several reported that it was their first formal exposure to organized MRI safety material. This sparked demands for more frequent and integrated training in their curricula. "The questions force us to think about real clinical practices," a few students said. Even the students who struggled with the assessment felt that it was an applied, real-world task. The high engagement rate and feedback scores demonstrate that students favor more focused, well-guided safety teaching and are receptive to modules that encourage reflective, critical thinking in their real-world imaging context.

All in all, reviews confirm that the module was well received. It did a good job in generating awareness and may really help to influence future curriculum decisions. And it indicates that such modules should be rolled out in other diagnostic areas and academic levels to enhance safety competency in radiology education.

- Consistently, there is no previous training that provides a clear goal for organized educational reform.
- Knowledge grows in predictable ways academically, though even the most advanced learners have gaps.
- Handson simulation and disaster preparedness are desired at all levels.
- The feedback was overwhelmingly positive and seemed open to more organized modules.

4.11. Limitations and Future Work

Despite the significant findings and strong educational impact demonstrated in this study, certain limitations must be acknowledged. Firstly, the study employed a single-group pre-test and post-test design without a control group, which limits the ability to establish definitive causal relationships between the intervention and observed outcomes. Although the results showed highly significant improvements, the absence of a comparator group may introduce potential internal validity concerns. Secondly, the study focused on short-term knowledge assessment immediately after the intervention, without evaluating long-term retention or sustained behavioral changes in clinical practice. As a result, it remains unclear whether the acquired knowledge and skills would persist over time or translate into consistent real-world application. Additionally, some aspects of the study, particularly confidence and preparedness, were assessed using self-reported measures, which may be subject to response bias or overestimation of abilities.

Furthermore, while the study included multiple institutions, the sample was limited to selected universities within India, which may affect the generalizability of findings to other geographical regions or healthcare systems. Differences in curriculum structure, resource availability, and institutional practices across countries may influence the applicability of the results. Another limitation identified through qualitative feedback was the limited duration of practical and simulation-based training, which may have restricted deeper skill development and hands-on experience. Although the module was effective in improving knowledge, extended practical exposure could further enhance competency and clinical readiness.

In light of these limitations, several recommendations for future research and implementation are proposed. Future studies should adopt randomized controlled trial (RCT) designs to strengthen causal inference and provide higher levels of evidence. Longitudinal studies are also recommended to assess long-term knowledge retention, skill sustainability, and impact on actual clinical practice and patient safety outcomes. Additionally, integrating MRI safety education into the formal curriculum at undergraduate and postgraduate levels would ensure early and consistent exposure to safety principles. Expanding the module to include advanced simulation-based training and repeated refresher sessions could further improve practical competence and reinforce learning over time.

Moreover, future research should explore the inclusion of interdisciplinary participants, such as physicians, nurses, and allied healthcare professionals, to promote a comprehensive safety culture within healthcare settings. The development of digital and e-learning platforms for MRI safety education may enhance accessibility, scalability, and standardization of training across institutions. Finally, multicenter international studies are recommended to validate the findings across diverse healthcare systems and establish globally applicable MRI safety education models.

Overall, addressing these limitations and implementing the recommended strategies will strengthen the effectiveness, sustainability, and global relevance of MRI safety education, ultimately contributing to improved patient safety and quality of care.

5. DISCUSSION

The present study aimed to evaluate the effectiveness of a structured MRI safety educational module in improving knowledge, awareness, and clinical preparedness among radiology students. The findings from both pre-assessment and post-assessment phases provide compelling evidence of the significant impact of targeted educational interventions in addressing critical gaps in MRI safety knowledge.

5.1 Interpretation of Pre-Assessment Findings

The pre-assessment results revealed critically inadequate baseline knowledge, with a mean score of 3.18/7 (45.4%), indicating that the majority of participants lacked fundamental understanding of MRI safety principles. More than half of the students scored below the minimum acceptable threshold, highlighting a serious deficiency in safety awareness.

A key observation was the presence of a clear knowledge gradient across academic levels, where postgraduate students performed better than undergraduate and diploma students. However, even advanced learners failed to consistently achieve optimal competency levels. This suggests that although knowledge improves with academic progression, MRI safety education is not systematically reinforced within existing curricula.

Additionally, the uniformly low performance across all domains—including implant safety, MRI zones, and emergency procedures—indicates that the deficiency is systemic rather than topic-specific. The absence of significant differences across institutions further reinforces that this gap is widespread and not limited to a particular educational setting.

Collectively, these findings underscore the urgent need for structured, standardized MRI safety training, particularly at early stages of medical and radiological education.

5.2 Impact of Educational Intervention (Post-Assessment Findings)

Following the implementation of the MRI safety module, a dramatic improvement in knowledge was observed, with mean scores increasing to 6.21/7 (88.7%). This represents a 95.3% improvement, demonstrating the effectiveness of the intervention in enhancing both conceptual understanding and practical awareness.

The extremely large effect size (Cohen's d = 2.89) indicates that the educational module had a strong and clinically meaningful impact, far exceeding typical outcomes reported in educational research.

Another important finding was the significant reduction in variability of scores, as reflected by the decrease in standard deviation from 1.84 to 0.73.

This suggests that the intervention not only improved overall knowledge but also ensured consistent learning outcomes across all participants, including those with initially low baseline knowledge.

Furthermore, the near elimination of low-performing students (from 54.5% to 0.2%) demonstrates that the module effectively addressed critical knowledge deficiencies, ensuring that almost all participants achieved competency-level performance.

5.3 Resolution of Knowledge Disparity and Educational Equity

One of the most significant outcomes of the study was the reduction in knowledge inequality across academic levels. The knowledge gap between highest and lowest performers decreased by 67%, indicating that the intervention successfully standardized knowledge levels.

Interestingly, the greatest relative improvement was observed among early-stage learners, particularly first-year B.Sc. and diploma students, who demonstrated improvements exceeding 300%. This suggests that the module is particularly effective in addressing foundational gaps in knowledge, making it highly suitable for early integration into educational curricula.

At the same time, advanced learners also showed measurable improvement, confirming the universal applicability of the module across different levels of training.

5.4 Clinical Relevance and Practical Implications

The improvement observed in post-assessment was not limited to theoretical knowledge but extended to clinical preparedness and decision-making ability. This is supported by the significant reduction in:

- Confidence deficiency (85% → 5%)
- Emergency uncertainty (92% → 18%)
- Procedural gaps (76% → 6%)

These findings indicate that the intervention successfully bridged the gap between knowledge and clinical application, which is essential in MRI environments where safety risks can have serious consequences.

The domain-wise improvement across critical areas such as implant safety, RF burns, and emergency procedures further highlights the clinical relevance of the module. These are high-risk areas where errors can directly compromise patient safety, and the observed improvement suggests that the intervention has the potential to reduce such risks in real-world practice.

5.5 Integration of Quantitative and Qualitative Findings

The qualitative findings from student interviews strongly support the quantitative results. Participants reported improved engagement, better understanding, and increased confidence in handling MRI-related situations.

The feedback that the module was interactive, practical, and clinically relevant reinforces its effectiveness in addressing the limitations of traditional lecture-based teaching. Additionally, student recommendations for curriculum integration and repeated training highlight the perceived value and sustainability of the intervention.

The convergence of quantitative improvements and qualitative satisfaction provides strong evidence for the validity, reliability, and acceptability of the educational module.

5.6 Comparison with Existing Literature

The findings of this study are consistent with previous research indicating that MRI safety knowledge among students and healthcare professionals is generally inadequate prior to structured training. Similar studies have reported that lack of formal education leads to increased risk of safety incidents and poor adherence to protocols.

The significant improvement observed after the intervention aligns with literature demonstrating the effectiveness of simulation-based and structured educational approaches in improving knowledge retention and clinical preparedness.

However, the magnitude of improvement observed in this study, particularly the extremely large effect size and reduction in knowledge disparity, suggests that the developed module may be more comprehensive and impactful than conventional training methods.

6. CONCLUSION

The present study provides compelling evidence that MRI safety knowledge among radiology students is critically inadequate at baseline, posing potential risks to patient safety and clinical practice. The pre-assessment findings revealed widespread deficiencies across all domains of MRI safety, with significant gaps in understanding of critical areas such as implant safety, MRI zones, and emergency procedures. These deficiencies were consistent across institutions and academic levels, indicating a systemic shortcoming in existing educational frameworks.

Following the implementation of the structured MRI safety educational module, a dramatic and statistically significant improvement was observed in knowledge, confidence, and clinical preparedness. The mean score increased from 45.4% to 88.7%, with an extremely large effect size, demonstrating the high effectiveness of the intervention. The near elimination of low-performing students and the substantial reduction in knowledge disparity highlight the module's ability to achieve uniform competency across diverse learner groups.

Importantly, the intervention not only enhanced theoretical understanding but also improved clinical confidence, decision-making ability, and preparedness for real-world MRI practice. The strong alignment between quantitative improvements and qualitative feedback further validates the practical relevance, acceptability, and learner-centered design of the module.

The findings of this study underscore the urgent need to integrate structured MRI safety education into formal radiology curricula, particularly at the undergraduate level, where foundational knowledge is established. The demonstrated effectiveness, scalability, and adaptability of the module suggest that it can serve as a standardized model for MRI safety training across institutions.

In conclusion, the developed MRI safety educational module represents a highly effective, evidence-based intervention that significantly enhances knowledge, reduces educational disparities, and promotes safe clinical practice. Its widespread implementation has the potential to improve patient safety, reduce MRI-related risks, and strengthen the overall quality of radiological care.

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