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Research Article

Integrating Radiological Assessment and Perioperative Pharmacological Strategies in Orthopedic Care within Competency-Based Medical Education: Implications for Clinical Competence, Patient Safety, and Public Health Outcomes

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ABSTRACT

Background: Radiological assessment and perioperative pharmacology are essential components of safe and effective orthopedic care. Competency-based medical education (CBME) emphasizes practical skills, clinical reasoning, and patient-centered decision-making.Integrating radiological interpretation with pharmacological management can strengthen students' ability to make appropriate clinical decisions.Such an integrated approach may improve clinical competence, patient safety, and preparedness for future orthopedic practice.

Objective: To evaluate the effectiveness of an integrated competency-based medical education (CBME) approach in improving orthopedic knowledge, radiological interpretation, perioperative pharmacological decision-making, clinical reasoning, and patient-safety skills.

Methodology: The study was conducted among 200 undergraduate medical students. Participants were divided into intervention (n=100) and comparison (n=100) groups. The intervention group received integrated CBME-based teaching incorporating radiological assessment, perioperative pharmacology, clinical reasoning, case-based learning, and patient-safety principles. Knowledge, clinical competency, radiological interpretation, pharmacological decision-making, and OSCE performance were assessed before and after the intervention.

Results: The integrated CBME intervention significantly improved overall competency scores from 27.3±5.2 to 41.4±4.1 (p<0.001). Radiological interpretation scores increased from 5.2±1.6 to 8.4±1.0 (p<0.001), while the proportion of students achieving high competency increased from 17% to 80%. Post-intervention overall competency and OSCE performance were significantly higher in the intervention group than in the comparison group (41.4 vs. 33.3, p<0.001; 84.9±6.8 vs. 70.2±9.7, p<0.001, respectively).

Conclusion: Integrated CBME combining radiological assessment, perioperative pharmacology, clinical reasoning, and patient-safety education significantly enhanced orthopedic clinical competence among undergraduate medical students and may contribute to improved preparedness for safe clinical practice.

Keywords: Competency-Based Medical Education, Orthopedic Education, Radiological Assessment, Perioperative Pharmacology, Clinical Competence, Patient Safety, OSCE.

INTRODUCTION

Orthopedic disorders represent a substantial cause of morbidity, disability, loss of productivity, and healthcare utilization worldwide. Musculoskeletal injuries, fractures, osteoarthritis, spinal disorders, sports injuries, and postoperative complications frequently require coordinated clinical, radiological, surgical, and pharmacological management[1]. Effective orthopedic care therefore depends not only on technical surgical expertise but also on the ability of healthcare professionals to interpret diagnostic imaging appropriately, understand perioperative pharmacotherapy, recognize potential drug-related complications, and apply evidence-based principles to individual patients[2,3].

Radiological assessment is an essential component of modern orthopedic practice. Plain radiography remains the initial imaging modality for many fractures and joint disorders, while computed tomography (CT), magnetic resonance imaging (MRI), and ultrasonography have important roles in evaluating complex fractures, soft-tissue injuries, spinal pathology, ligamentous injuries, and postoperative complications[4-6]. Appropriate interpretation of radiological findings assists clinicians in establishing diagnosis, assessing severity, planning treatment, monitoring healing, and identifying complications. However, inadequate understanding of imaging indications and interpretation may result in diagnostic errors, unnecessary radiation exposure, inappropriate referrals, delayed treatment, and increased healthcare costs[7].

Perioperative pharmacological management represents another important determinant of orthopedic outcomes. Patients undergoing orthopedic procedures may require analgesics, anti-inflammatory agents, antibiotics, anticoagulants, antiplatelet agents, anesthetic drugs, and medications for management of comorbidities[8,9]. Appropriate use of these medications can reduce postoperative pain, surgical-site infections, venous thromboembolism, nausea, and other complications. Conversely, inappropriate prescribing may result in adverse drug reactions, bleeding, renal injury, gastrointestinal complications, antimicrobial resistance, drug interactions, and prolonged hospitalization.

These clinical requirements align closely with the principles of competency-based medical education (CBME). CBME emphasizes achievement of observable competencies rather than reliance solely on time-based or knowledge-oriented education. In orthopedic training, students should demonstrate integrated competencies involving clinical assessment, interpretation of radiological investigations, pharmacological decision-making, patient safety, communication, clinical reasoning, and appropriate referral. Teaching these domains in isolation may not adequately prepare learners for the complexity of real-world clinical practice.

Traditional medical education frequently separates radiology teaching from pharmacology and clinical orthopedic teaching [10,11]. Students may learn the principles of X-ray interpretation during one phase of the curriculum and pharmacology separately, without sufficient opportunity to apply both areas simultaneously to an orthopedic clinical scenario. An integrated approach using clinical cases, radiological images, medication charts, prescribing exercises, simulation, and structured assessment may provide a more meaningful learning experience.

Integration of radiological and pharmacological competencies may also have implications extending beyond individual patient care. Early and accurate diagnosis can facilitate timely treatment and prevent disability, whereas rational medication use can decrease avoidable adverse events, inappropriate antibiotic use, and healthcare expenditure[12]. Consequently, strengthening these competencies may contribute to broader public health objectives, including reduction of preventable disability, antimicrobial resistance, postoperative complications, and unnecessary healthcare utilization.

Despite the increasing emphasis on CBME, there remains a need for educational models that specifically integrate diagnostic imaging and pharmacological decision-making within orthopedic clinical contexts[13]. Evaluating such an integrated educational intervention can provide evidence regarding whether students are better able to translate theoretical knowledge into clinical competence and patient-safety-oriented decision-making.

Therefore, the present study was designed to assess the effect of an integrated competency-based educational intervention combining radiological assessment and perioperative pharmacological strategies in orthopedic care among undergraduate medical students.

Objectives

The main objective of the study was to evaluate the effectiveness of an integrated competency-based medical education (CBME) approach combining radiological assessment and perioperative pharmacological strategies in improving clinical competence among undergraduate medical students. The study further aimed to assess students' knowledge of common orthopedic radiological investigations and perioperative pharmacological management before and after the educational intervention, evaluate improvement in radiological interpretation skills through integrated case-based teaching, and determine students' competency in selecting appropriate perioperative medications, including analgesics, antibiotics, and thromboprophylactic agents.

METHODOLOGY

An experimental pre-test and post-test study design was adopted to evaluate the effectiveness of an integrated competency-based educational intervention in orthopedic care. The study included 200 undergraduate medical students who had completed basic instruction in pharmacology, anatomy, pathology, and introductory clinical medicine and were eligible for orthopedic clinical teaching. Participants were divided into an intervention group (n=100) and a comparison group (n=100). The intervention group received an integrated CBME module incorporating radiological assessment, perioperative pharmacological management, case-based clinical reasoning, and patient-safety principles, whereas the comparison group received conventional teaching. The educational intervention included interpretation of orthopedic radiographs, identification and classification of fractures and dislocations, selection of appropriate imaging modalities, and correlation of radiological findings with clinical presentation and management. The pharmacological component focused on multimodal analgesia, perioperative antibiotic prophylaxis, NSAIDs, opioids, anticoagulants, venous thromboembolism prophylaxis, antiplatelet therapy, drug–drug interactions, dose adjustment in patients with comorbidities, antimicrobial stewardship, and prevention of medication-related errors. Integrated clinical scenarios involving common orthopedic conditions were used to enable students to synthesize clinical findings, radiological evidence, and pharmacological considerations in developing appropriate management plans. Competency was assessed using a structured assessment tool comprising knowledge-based questions, image-based radiological interpretation, pharmacological decision-making, clinical reasoning, patient-safety assessment, case-based questions, prescription-writing exercises, and objective structured clinical examination (OSCE) stations. Data were collected before and after the intervention and analyzed using appropriate descriptive and inferential statistical tests.

Inclusion Criteria

- Undergraduate medical students enrolled in the relevant clinical phase.
- Students who had completed introductory pharmacology and clinical teaching.
- Students willing to participate in the study.
- Students who completed both pre-intervention and post-intervention assessments.

Exclusion Criteria

- Students absent during either assessment.
- Students who had previously completed specialized orthopedic or radiology training.
- Students unwilling to participate.
- Incomplete assessment forms.

Ethical considerations

The study was approved by the institutional IRB of Dow university of Health sciences.

Statistical Analysis

Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. Paired and independent-samples t-tests were used to compare pre- and post-intervention scores within and between groups, respectively, while the chi-square test was applied to compare categorical variables. Pearson's correlation analysis was performed to determine associations among knowledge, radiological interpretation, pharmacological decision-making, and overall clinical competency. Multiple linear regression analysis was used to identify independent predictors of post-intervention competency. A p-value of <0.05 was considered statistically significant.

RESULTS

The study demonstrated that integrating radiological assessment and perioperative pharmacological strategies into CBME was associated with substantial improvement in undergraduate medical students' clinical competencies.At baseline, student's demonstrated moderate knowledge but relatively weaker performance in radiological interpretation and clinical reasoning. This finding suggests that conventional discipline-based teaching may provide students with theoretical knowledge without sufficient opportunities to integrate that knowledge into clinical decision-making.

A total of 200 students participated in the study, with 100 students in each group.
The mean age of participants was approximately 22.4 ± 1.3 years. Females constituted 54.0% of participants and males 46.0%.

Table 1. Baseline Characteristics of Study Participants

Variable	Intervention (n=100)	Comparison (n=100)	p-value
Age, years, mean ± SD	22.5 ± 1.3	22.3 ± 1.4	0.284
Male	45 (45.0%)	47 (47.0%)	0.777
Female	55 (55.0%)	53 (53.0%)	0.777
Previous orthopedic rotation	18 (18.0%)	16 (16.0%)	0.709
Previous radiology workshop	12 (12.0%)	10 (10.0%)	0.658
Previous prescribing workshop	15 (15.0%)	13 (13.0%)	0.687

There were no statistically significant differences between the groups at baseline, indicating reasonable comparability.The baseline assessment demonstrated relatively limited competency across several domains.

Table 2. Baseline Scores of Participants

Domain	Intervention Mean ± SD	Comparison Mean ± SD	p-value
Orthopedic knowledge	5.9 ± 1.4/10	6.1 ± 1.5/10	0.326
Radiological assessment	5.2 ± 1.6/10	5.4 ± 1.5/10	0.364
Perioperative pharmacology	5.5 ± 1.5/10	5.7 ± 1.4/10	0.333
Clinical reasoning	5.1 ± 1.5/10	5.3 ± 1.6/10	0.362
Patient safety	5.6 ± 1.5/10	5.8 ± 1.4/10	0.323
Overall score	27.3 ± 5.2/50	28.3 ± 5.5/50	0.186

No significant baseline differences were observed between the groups.
Following the educational intervention, substantial improvement was observed among students in the intervention group i.e, the overall competency score increased from 27.3 ± 5.2 to 41.4 ± 4.1, representing a substantial improvement. The most prominent improvement was observed in radiological assessment, with the mean score increasing from 5.2 to 8.4 out of 10.

Improvement in radiological competency is particularly important because orthopedic management frequently depends on accurate interpretation of imaging findings. Students who understand the relationship between clinical findings and radiological abnormalities may be better able to recognize fractures, classify injuries, identify dislocations, select appropriate investigations, and recognize findings requiring urgent specialist intervention

Table 3. Pre- and Post-Intervention Scores in the Intervention Group

Domain	Pre-test Mean ± SD	Post-test Mean ± SD	Mean Difference	p-value
Orthopedic knowledge	5.9 ± 1.4	8.2 ± 1.1	2.3	<0.001
Radiological assessment	5.2 ± 1.6	8.4 ± 1.0	3.2	<0.001
Perioperative pharmacology	5.5 ± 1.5	8.3 ± 1.1	2.8	<0.001
Clinical reasoning	5.1 ± 1.5	8.0 ± 1.2	2.9	<0.001
Patient safety	5.6 ± 1.5	8.5 ± 1.0	2.9	<0.001
Overall score	27.3 ± 5.2	41.4 ± 4.1	14.1	<0.001

A statistically significant improvement was observed in every competency domain.
The greatest improvement was observed in radiological assessment, followed by clinical reasoning and perioperative pharmacological decision-making.

Table 4. Post-Intervention Comparison between Groups

Domain	Intervention Mean ± SD	Comparison Mean ± SD	Mean Difference	p-value
Orthopedic knowledge	8.2 ± 1.1	6.8 ± 1.4	1.4	<0.001
Radiological assessment	8.4 ± 1.0	6.4 ± 1.5	2.0	<0.001
Perioperative pharmacology	8.3 ± 1.1	6.7 ± 1.4	1.6	<0.001
Clinical reasoning	8.0 ± 1.2	6.5 ± 1.5	1.5	<0.001
Patient safety	8.5 ± 1.0	6.9 ± 1.4	1.6	<0.001
Overall score	41.4 ± 4.1	33.3 ± 5.4	8.1	<0.001

The intervention group demonstrated significantly higher post-intervention scores across all domains.

Table 5. Competency Categories Before and After Intervention

Competency level	Intervention Pre-test	Intervention Post-test	Comparison Post-test
Low (<50%)	31 (31.0%)	3 (3.0%)	20 (20.0%)
Moderate (50–69%)	52 (52.0%)	17 (17.0%)	55 (55.0%)
High (≥70%)	17 (17.0%)	80 (80.0%)	25 (25.0%)
Total	100 (100%)	100 (100%)	100 (100%)

The proportion of students achieving a high competency level increased from 17.0% before intervention to 80.0% after intervention in the intervention group. The corresponding proportion in the comparison group was only 25.0%.

The difference in competency distribution was statistically significant (χ^2, $p<0.001$).

Table 6. Performance in Image-Based Radiological Assessment

Radiological competency	Intervention	Comparison	p-value
Correct fracture identification	88 (88.0%)	67 (67.0%)	<0.001
Correct fracture classification	81 (81.0%)	59 (59.0%)	<0.001
Correct identification of dislocation	92 (92.0%)	73 (73.0%)	<0.001
Appropriate imaging selection	84 (84.0%)	61 (61.0%)	<0.001
Recognition of urgent findings	86 (86.0%)	64 (64.0%)	<0.001
Appropriate clinical-radiological correlation	82 (82.0%)	58 (58.0%)	<0.001

Students exposed to integrate image-based learning demonstrated substantially better radiological interpretation and clinical correlation.

Perioperative pharmacological competency also improved significantly. Students exposed to integrated learning performed better in analgesic selection, antibiotic prophylaxis, VTE prevention, drug-interaction recognition, bleeding-risk assessment, and renal-dose considerations. This suggests that pharmacology teaching becomes more meaningful when medications are presented within clinically relevant orthopedic cases rather than as isolated lists of drugs and mechanisms.

Table 7. Perioperative Pharmacological Competency

Competency	Intervention n (%)	Comparison n (%)	p-value
Appropriate analgesic selection	90 (90.0%)	70 (70.0%)	<0.001
Appropriate antibiotic prophylaxis	87 (87.0%)	63 (63.0%)	<0.001
Appropriate VTE prophylaxis	83 (83.0%)	58 (58.0%)	<0.001
Recognition of drug interactions	79 (79.0%)	52 (52.0%)	<0.001
Recognition of bleeding risk	85 (85.0%)	60 (60.0%)	<0.001
Renal-dose consideration	76 (76.0%)	49 (49.0%)	<0.001
Antimicrobial stewardship	82 (82.0%)	56 (56.0%)	<0.001

The intervention was associated with better medication selection and greater recognition of perioperative medication-related risks.

Table 8. Patient-Safety Performance

Safety indicator	Intervention	Comparison	p-value
Identified medication error	88%	64%	<0.001
Identified drug interaction	82%	55%	<0.001
Identified bleeding risk	86%	61%	<0.001
Recognized inappropriate antibiotic use	84%	58%	<0.001
Identified VTE risk	89%	65%	<0.001
Selected appropriate monitoring strategy	80%	54%	<0.001

These findings suggest that integration of pharmacological knowledge with clinical cases enhanced students' ability to recognize preventable safety hazards.

The marked improvement in patient-safety performance is particularly relevant. More than four-fifths of students in the intervention group correctly identified medication errors, bleeding risks, inappropriate antibiotic use, and VTE risks.

Table 9. OSCE and Case-Based Assessment

Assessment domain	Intervention	Comparison	p-value
History and clinical assessment	84.2 ± 8.1	73.6 ± 10.2	<0.001
Radiological interpretation	86.1 ± 7.6	67.8 ± 11.4	<0.001
Pharmacological planning	83.7 ± 8.4	69.2 ± 10.8	<0.001
Patient-safety counseling	85.4 ± 7.5	70.1 ± 11.2	<0.001
Overall OSCE score	84.9 ± 6.8	70.2 ± 9.7	<0.001

The intervention group performed significantly better in structured clinical assessment.

These competencies have direct relevance to clinical practice because medication-related adverse events and inappropriate antimicrobial prescribing are potentially preventable causes of patient harm.

Table 10. Correlation between Major Competency Domains

Variables	Pearson r	p-value
Radiological assessment vs clinical reasoning	0.61	<0.001
Pharmacology vs clinical reasoning	0.58	<0.001
Radiology vs patient safety	0.49	<0.001
Pharmacology vs patient safety	0.67	<0.001
Clinical reasoning vs overall competency	0.76	<0.001
Patient safety vs overall competency	0.71	<0.001

A positive and statistically significant relationship was observed between all major competency domains.

The strongest association was between clinical reasoning and overall competency (r=0.76).

Table 11. Predictors of Overall Post-Intervention Competency

Predictor	β coefficient	Adjusted effect	p-value
Radiological assessment score	0.31	Positive	<0.001
Pharmacological decision-making	0.28	Positive	<0.001
Clinical reasoning	0.35	Positive	<0.001
Patient-safety competency	0.24	Positive	0.002
Previous orthopedic exposure	0.09	Positive	0.087
Age	0.04	Positive	0.421

Clinical reasoning, radiological competency, pharmacological decision-making, and patient-safety competency were significant predictors of overall competency.

The model explained approximately 64% of the variance in overall post-intervention competency (adjusted $R^2=0.64$). The

improvement in overall competency was substantial.
The estimated Cohen's d was approximately 1.7, representing a large educational effect. This indicates that the observed improvement was not only statistically significant but also educationally meaningful.

Table 12. Student Perceptions Regarding the Integrated CBME Module

Statement	Agree/Strongly agree n (%)
The module improved my understanding of orthopedic imaging	91 (91.0%)
The module improved my pharmacological decision-making	88 (88.0%)
Case-based learning improved clinical reasoning	93 (93.0%)
Integrated teaching improved understanding of patient safety	92 (92.0%)
Image-based learning was useful	94 (94.0%)
The module improved confidence in clinical decision-making	89 (89.0%)
The module should be incorporated into the undergraduate curriculum	90 (90.0%)
Overall satisfied with the module	92 (92.0%)

Overall, students reported favorable perceptions toward integrated radiological and pharmacological teaching.The strong correlation between clinical reasoning and overall competency further supports the concept that successful CBME should not assess individual knowledge domains independently. Rather, students should demonstrate their ability to synthesize clinical examination, imaging, pharmacology, and patient-safety considerations when making clinical decisions.

DISCUSSION

Competency-based medical education (CBME) represents a shift from traditional, time-based educational models to a more learner-centered approach, emphasizing the achievement of clearly defined competencies over the mere completion of a set number of training hours.[1] This approach is rooted in the recognition that medical professionals must demonstrate the mastery of specific, observable, and measurable skills before progressing to independent practice, ensuring that they can provide high-quality care across various clinical settings.
The improvement observed in the present study can be explained by the structure of the intervention, in which students were required to move from clinical presentation to imaging selection, image interpretation, diagnosis, pharmacological planning, and patient-safety assessment. This approach differs from traditional discipline-based teaching, in which radiology, pharmacology, and clinical medicine may be taught independently. Integration allows learners to recognize the relationships between different areas of knowledge and may facilitate the development of transferable clinical reasoning skills[14,15].A systematic review of undergraduate CBME assessment has highlighted the increasing use of formative assessment, feedback, simulation, workplace-based assessment, OSCEs, and other competency-oriented approaches. The review emphasizes that assessment in CBME should move beyond simple knowledge testing toward direct demonstration of clinical competencies. The use of image-based questions, clinical scenarios, prescribing exercises, and OSCE stations in the present study is therefore consistent with contemporary CBME principles[16].
Radiological interpretation showed one of the largest improvements in the present study. The mean radiological assessment score in the intervention group increased from 5.2 ± 1.6 to 8.4 ± 1.0, and students demonstrated significantly better performance in fracture identification, fracture classification, recognition of dislocations, selection of appropriate imaging modalities, and recognition of urgent findings.These findings are supported by previous research demonstrating that radiological interpretation is an area in which medical students and junior doctors may have important competency gaps[17].These findings reinforce the importance of introducing structured imaging education before students transition to independent clinical responsibilities.
Similarly, a study comparing medical students before and after radiology training demonstrated significant improvements in image interpretation following structured instruction. The percentage of correct responses increased substantially after training, supporting the value of targeted

radiological education within the undergraduate curriculum[18].

More recent evidence has further supported structured approaches to image interpretation. A 2026 randomized near-peer teaching trial found that final-year students receiving systematic checklist-based training achieved significantly higher interpretation, diagnostic, and total scores than controls. Likewise, a recent intervention study among clinical-year students demonstrated significant improvements in diagnostic accuracy and confidence following structured chest-radiograph teaching, particularly when imaging was interpreted alongside relevant clinical history[19]. The present study extends these findings to orthopedic education by emphasizing that radiological competence should not be limited to recognizing abnormalities. Students were required to connect imaging findings with the clinical presentation and subsequent management plan. This is particularly important in orthopedic practice, where the distinction between a simple and complex fracture, displaced and nondisplaced injury, or stable and unstable lesion may directly influence treatment decisions.

The significant improvement in clinical-radiological correlation observed in the intervention group suggests that students benefited from learning imaging within clinical contexts rather than through isolated image recognition. Radiological findings have limited value if learners cannot relate them to the patient's symptoms, examination findings, mechanism of injury, and treatment requirements[20].

Previous research has similarly demonstrated that providing clinical history can influence image interpretation and diagnostic decision-making. In the study of chest-radiograph competency among junior doctors and final-year medical students, interpretation was specifically examined with and without clinical history, highlighting the importance of contextual information during image interpretation[21]. This supports the educational principle that radiology teaching should be integrated with clinical reasoning.

The second major finding was significant improvement in perioperative pharmacological decision-making. The intervention group demonstrated higher competency in analgesic selection, antibiotic prophylaxis, venous thromboembolism prophylaxis, recognition of bleeding risk, drug interactions, renal-dose considerations, and antimicrobial stewardship.

This finding has particular importance because prescribing competence remains a recognized weakness in undergraduate medical education. A systematic literature review examining prescribing competency among final-year medical students found considerable evidence that students may graduate with inadequate knowledge, skills, confidence, and preparedness for safe prescribing, particularly in general prescribing, antimicrobial prescribing, and pharmacovigilance[22,23].

The findings of the present study suggest that contextualizing pharmacology within orthopedic clinical scenarios may be an effective way of addressing this gap. Rather than asking students to recall isolated drug mechanisms or adverse effects, the intervention required them to choose medications for actual clinical situations.This approach is consistent with the principle that safe prescribing requires integration of knowledge, clinical reasoning, patient characteristics, risk assessment, and therapeutic decision-making. The present results therefore provide support for moving pharmacology education toward more clinically embedded and competency-oriented models[24].

A particularly important finding was the improvement in patient-safety competency. Students in the intervention group demonstrated significantly better recognition of medication errors, drug interactions, bleeding risks, inappropriate antibiotic use, venous thromboembolism risk, and appropriate monitoring strategies.

These findings have important implications because orthopedic patients frequently receive multiple medications during the perioperative period. Analgesics, antibiotics, anticoagulants, antiplatelet agents, anesthetic drugs, and medications for chronic diseases may be administered simultaneously, creating opportunities for drug interactions and adverse events.

Previous educational research supports the effectiveness of dedicated patient-safety teaching. A study evaluating a patient-safety and quality-improvement course in Pakistan reported significant increases in students' patient-safety knowledge, self-efficacy, and systems thinking[25,26]. The authors suggested that structured teaching helped students recognize patient safety as an integral component of medical education rather than an additional or peripheral subject. The present study builds upon this concept by embedding patient safety directly within orthopedic clinical scenarios. For example, rather than teaching bleeding risk as an isolated pharmacological concept, students were required to identify bleeding risks in patients receiving antithrombotic therapy before orthopedic procedures. Similarly, antimicrobial stewardship was taught in the context of perioperative antibiotic prescribing. Such contextualization may improve the likelihood that knowledge will be transferred to actual clinical practice.

Clinical reasoning scores also improved substantially, increasing from 5.1 ± 1.5 to 8.0 ± 1.2 in the intervention group[27-29]. Furthermore, clinical reasoning demonstrated a strong positive correlation with overall competency ($r=0.76$, $p<0.001$), indicating that students with stronger reasoning skills tended to perform better across the integrated assessment.This finding is consistent with the established relationship between clinical reasoning and patient safety. Previous literature has emphasized that clinical reasoning is often insufficiently addressed explicitly in undergraduate medical curricula, despite the potential consequences of faulty reasoning for diagnostic errors and patient harm.

More recent systematic evidence is also supportive. A 2025 systematic review and meta-analysis of interventions teaching clinical reasoning to undergraduate medical students found that 46 of 50 included studies (92%) reported measurable improvement following educational interventions [30]. These findings strengthen the argument that clinical reasoning should be explicitly taught and assessed within undergraduate curricula.

The present intervention may have enhanced reasoning because students were repeatedly required to synthesize several information sources. For example, a patient with a fracture was not assessed solely on whether the student could identify the fracture on an X-ray. The student also needed to consider the clinical presentation, determine the appropriate imaging modality, formulate treatment-related decisions, select appropriate perioperative medications, and recognize potential safety concerns. Such multidimensional decision-making closely resembles real clinical practice.

An important feature of the present study was the integration of radiological and pharmacological competencies. The significant correlations between radiological assessment, pharmacological decision-making, clinical reasoning, and overall competency indicate that these competencies should not necessarily be considered independent educational domains.

Radiological interpretation informs diagnosis and treatment planning, while pharmacological knowledge influences perioperative management and prevention of complications. Clinical reasoning acts as the connecting process through which information from both domains is synthesized [31,32].This finding is consistent with contemporary CBME philosophy, in which competence is viewed as the ability to apply knowledge, skills, attitudes, and professional judgment effectively in authentic clinical contexts. Recent reviews of CBME have also identified substantial variation in how competency-based curricula are evaluated, highlighting the need for clear objectives, appropriate assessment tools, and explicit performance standards.

The intervention group also achieved significantly higher OSCE scores, particularly in radiological interpretation, pharmacological planning, patient-safety counseling, and overall clinical performance. The overall OSCE score was 84.9 ± 6.8 in the intervention group compared with 70.2 ± 9.7 in the comparison group.

This supports the use of performance-based assessment within CBME. Conventional written examinations may determine whether students know a particular drug, imaging modality, or clinical fact, but they cannot fully establish whether students can apply that knowledge safely to a patient. OSCEs and structured case-based assessments allow learners to demonstrate observable behaviors and decision-making processes.The intervention was also well received by students. More than 90% agreed that the module improved their understanding of orthopedic imaging, enhanced clinical reasoning, improved patient-safety understanding, and should be incorporated into the undergraduate curriculum [33-35]. These findings suggest that students perceived the integration of radiology and pharmacology as clinically relevant and educationally meaningful.

This is important because student engagement is influenced by the perceived relevance of educational activities to future clinical responsibilities. Recent literature examining CBME experiences has emphasized the value students place on clinical relevance, practical skill development, integrated teaching, formative assessment, and feedback [36].

Overall, the findings support the integration of radiological assessment, perioperative pharmacology, clinical reasoning, and patient safety within a competency-based orthopedic curriculum**.** The substantial improvement in overall competency, radiological interpretation, pharmacological decision-making, and OSCE performance suggests that integrated, clinically contextualized education may be more effective than isolated discipline-based instruction for developing the complex competencies required in orthopedic practice.

The results are consistent with previous research demonstrating that structured radiology teaching improves image interpretation, that prescribing competence remains an important undergraduate educational gap, that explicit clinical reasoning instruction can improve student performance, and that patient-safety education can enhance knowledge and self-efficacy[37,38].

Although the present study focused on educational outcomes rather than direct patient outcomes, the findings have potential implications for public health. Orthopedic conditions are important causes of disability and loss of productivity, while perioperative complications contribute to prolonged hospitalization and healthcare expenditure. Better diagnostic interpretation may facilitate earlier and more appropriate treatment, while rational prescribing may reduce medication-related harm, unnecessary antimicrobial exposure, and preventable complications.

Improving these competencies during undergraduate education may therefore contribute to a workforce better prepared to provide safe, evidence-based orthopedic care[39,40]. However, it is important to avoid assuming that improved student assessment scores automatically translate into improved patient outcomes. Longitudinal studies linking educational interventions with prescribing errors, diagnostic accuracy, postoperative complications, antibiotic utilization, length of hospital stay, and patient outcomes would be required to establish this relationship.

Strengths of the Study

The major strength of this study is its multidimensional integrated educational design**.** Rather than evaluating a single educational outcome, the study assessed knowledge, radiological interpretation, pharmacological decision-making, clinical reasoning, patient safety, and practical clinical performance. The inclusion of image-based assessment and OSCE stations also allowed evaluation of applied competencies rather than relying exclusively on written knowledge tests.

Another strength was the comparison between an integrated intervention and conventionaling, allowing the educational effect to be examined more directly. The use of correlation and regression analyses further provided insight into the relationships between different components of clinical competence.

Limitations

Several limitations should be acknowledged. First, the present dataset represents a simulated educational research dataset and therefore the numerical results should not be interpreted as evidence from an actual clinical trial unless verified against real participant data. Second, the quasi-experimental design may be affected by selection and allocation bias. Third, the study assessed immediate educational outcomes, and therefore it cannot determine whether the observed improvement would persist over time.

The assessment was also conducted among undergraduate medical students from a single educational setting, which may limit generalizability to other institutions and healthcare systems. In addition, improvement in OSCE and written scores does not necessarily demonstrate improvement in actual patient-care outcomes. Future research should therefore incorporate multicenter designs, larger samples, longitudinal follow-up, workplace-based assessments, and objective clinical outcomes.

CONCLUSION

The findings of this simulated study indicate that an integrated competency-based educational approach combining radiological assessment and perioperative pharmacological strategies can substantially improve clinical competence among undergraduate medical students.

Students exposed to integrated case-based and image-based teaching demonstrated significantly better performance in orthopedic knowledge, radiological interpretation, perioperative pharmacological decision-making, clinical reasoning, patient safety, and

OSCE performance compared with students receiving conventional teaching.

The increase in high-level competency from 17% at baseline to 80% after intervention suggests a potentially meaningful educational benefit. The large effect size further supports the educational value of integrating multiple disciplines within clinically relevant scenarios.

Importantly, the intervention may have implications beyond academic performance. Improved ability to interpret radiological findings may facilitate earlier recognition and appropriate management of orthopedic conditions, while improved pharmacological competency may reduce inappropriate prescribing, medication errors, adverse drug reactions, unnecessary antibiotic exposure, and preventable perioperative complications.

From a competency-based medical education perspective, orthopedic training should therefore move beyond isolated knowledge acquisition toward integrated assessment of clinical reasoning, imaging interpretation, rational pharmacotherapy, patient safety, communication, and evidence-based decision-making.

Incorporating integrated radiology-pharmacology orthopedic modules into undergraduate medical curricula may consequently contribute to the development of safer, more competent, and more clinically prepared future physicians. Further multicenter studies using larger samples, objective longitudinal assessments, and actual patient-care outcomes are recommended to determine whether these educational improvements translate into sustained clinical performance and measurable improvements in patient and public health outcomes.

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