



Construction and Application Exploration of an Emergency CT Case Library for Medical Imaging Technology Based on PBL Integrated with Virtual Simulation

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Abstract

The training of medical imaging technology professionals in the emergency field faces challenges such as tight clinical teaching resources, high-risk scenarios, and insufficient practical opportunities. To address the contradiction between traditional teaching models and the urgency and complexity of emergency medicine, this paper proposes and explores a new teaching model of constructing an emergency computed tomography (CT) case library based on “problem-based learning (PBL) integrated with virtual simulation technology”. The paper systematically expounds the construction concept, design principles, content framework, and key technical paths of the case library, elaborates on the design and implementation strategies of the PBL teaching process, and analyzes the teaching effect through preliminary application feedback. The research shows that this model can effectively simulate the real emergency environment, integrate theoretical knowledge, clinical decision-making, technical operations, image diagnosis, and team collaboration, providing students with a safe, controllable, and repeatable comprehensive training platform, which has significant practical value and promotion significance for cultivating high-quality, application-oriented medical imaging technology professionals who can quickly adapt to clinical positions.

Subject Areas

Educational Technology

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Keywords

PBL, Virtual Simulation, Medical Imaging Technology, Emergency CT, Case Library Construction

1. Introduction

In the modern medical system, the emergency department serves as the frontline for treating critically ill patients, and emergency CT examination, as a crucial auxiliary diagnostic method, plays a central role in the diagnosis and treatment processes of various acute conditions such as stroke, chest pain, and trauma due to its rapidity and large amount of information [1] [2]. This places extremely high demands on the radiographers performing CT examinations: they must possess solid knowledge of anatomy, medical physics, and equipment operation, as well as acute clinical judgment, efficient emergency response skills, precise scanning protocol optimization capabilities, and the ability to collaborate and communicate effectively with emergency physicians and nurses in high-pressure environments.

However, the current traditional medical imaging technology teaching model has significant shortcomings [3] [4]. For instance, the clinical practice barrier is high: the emergency department environment is unique, patients are critically ill, and their conditions change rapidly, and family members are emotionally tense, making it difficult for interns to obtain sufficient hands-on experience, especially when dealing with critically ill, uncooperative, or trauma patients, where the teaching risk is extremely high. The teaching scenarios are fragmented: traditional laboratory classes mostly focus on individual equipment operations or normal image recognition, while real emergency cases involve a continuous and dynamic process integrating “clinical history taking, condition assessment, scanning protocol decision-making, patient positioning and comfort, image acquisition and post-processing, initial quality control and diagnostic hints”. Traditional teaching cannot replicate this complete chain, leading to an imbalance in ability development: it overly emphasizes operational skills and image knowledge, while neglecting the cultivation of “high-level abilities” such as clinical thinking and decision-making based on limited information in emergencies, personalized adjustment of scanning protocols (such as low-dose and rapid scanning), and the initial identification and emergency communication of critical values (such as active bleeding and brain herniation). Additionally, there is an imbalance in teaching resources: high-quality teaching hospitals have abundant cases but limited teaching time, while lower-level institutions lack typical emergency cases.

To overcome these limitations, this study proposes the construction of an “emergency CT case library teaching model integrating PBL with virtual simulation technology”, aiming to explore a safe, controllable, repeatable, and systematic teaching path that integrates multi-dimensional knowledge and simulates the real emergency process, to help cultivate high-quality applied talents who can quickly adapt to clinical practice.

2. Core Concept: The Educational Integration Advantages of PBL and Virtual Simulation

2.1. The Connotation and Value of PBL Teaching Mode

PBL is a student-centered teaching model that starts with complex and real “problems”, and through group cooperation and independent exploration, students learn the scientific knowledge hidden behind the problems and develop problem-solving skills and autonomous learning abilities [5] [6]. In medical education, PBL can effectively promote the connection between basic theory and clinical practice, and cultivate students’ clinical reasoning, critical thinking, and lifelong learning habits. When applied to emergency CT teaching, it can integrate scattered knowledge points (such as cranial anatomy, CT parameters, stroke pathology) into specific clinical scenarios (such as “an elderly patient with sudden hemiplegia”), making the learning goals more targeted and intrinsically motivating.

2.2. The Teaching Support of Virtual Simulation Technology

Virtual simulation technology uses computers to generate highly realistic simulation environments, and students can interact with them through interactive devices [7] [8]. In medical education, it can create a safe environment, allowing students to repeatedly practice dealing with various critical situations in a risk-free virtual environment, even including the consequences of operational errors, without incurring any clinical risks. It can also replicate complex processes: high-fidelity simulation covers the entire process from patient arrival, emergency triage, communication with clinical doctors, equipment preparation, patient transportation, scanning, to image transmission. It enables visualization and repeatability of the process: abstract pathophysiological changes (such as the dynamic process of aneurysm rupture and bleeding) and the internal working principles of equipment (such as the impact of different reconstruction algorithms on image quality) can be visually presented. Additionally, classic cases are available for students to repeatedly study, analyze, and be assessed.

2.3. The Integration of PBL and Virtual Simulation

The virtual simulation case library provides an “immersive problem context carrier” for PBL, transforming a textually described case into a “virtual patient” and “virtual work scene” that is audible, visible, and interactive. Meanwhile, PBL infuses “inquiry-based learning spirit” into virtual simulation, preventing the technology from becoming a simple operation simulator and guiding students to delve from “how to do it” to “why to do it” and “how to do it better”. This integration creates a “learning based on virtual context problems”, achieving the unity of “knowledge, action, and thought”. The “dual-cycle PBL teaching model” referred to in this study means the close coupling of the autonomous inquiry cycle of PBL (problem analysis-knowledge construction-solution-reflection) and the practical verification cycle of virtual simulation (situation interaction-operation decision-result generation-feedback), forming a closed-loop learning process of “inquiry-

practice-reflection-re-inquiry”.

3. Construction of the Virtual Simulation Case Library for Emergency CT

3.1. Construction Principles

The construction of the case library is the cornerstone of the implementation of the teaching model and should follow the following principles: clinical authenticity—cases are derived from real emergency clinical work, with de-identification and educational design; the evolution of the condition, signs, and laboratory test results all conform to medical logic. Competency-oriented—each case focuses on cultivating a set of core competencies (such as the decision-making of scanning protocols for the acute chest pain triad). Progressive difficulty—the difficulty of the cases is set from simple to complex, from a single system (such as plain non-enhanced head CT) to the full process of multi-system trauma (whole-body CT), from clear indications to ambiguous ones. Multi-path interaction—key decision points are designed, and students’ different choices will lead to different process branches and outcomes (such as choosing the wrong scanning range leading to missed diagnosis, or improper communication causing complaints), and immediate feedback is provided.

3.2. Case and Image Data Acquisition and Transformation

The core data of the case library comes from the real and typical cases of the emergency CT room in the Department of Radiology of the First Affiliated Hospital of Wannan Medical College in the past three years. The data transformation process includes: 1) Ethical review and de-identification: With the approval of the hospital’s ethics committee, all personal information, such as names, ID numbers, and hospitalization numbers of all cases, is completely deleted or anonymized. 2) Case selection and “true value” determination: Two senior radiologists or above, based on the final clinical diagnosis, surgical pathology, or imaging follow-up results, jointly select cases that meet the teaching objectives and determine the key imaging signs (“true values”) and standardized scanning and post-processing protocols. 3) Teaching design: Integrate the complete clinical data (medical history, physical signs, laboratory tests) and the corresponding DICOM format CT images. The expert group designs the clinical manifestations, decision-making branch points, and expected learning objectives of the cases based on teaching principles. 4) Technical transformation: The de-identified image data, structured case scripts, and “true value” annotation information are handed over to the technical development team, which imports them into the virtual simulation engine to build an interactive three-dimensional virtual patient model and dynamic image generation logic.

3.3. Content Architecture

This case library adopts a modular design, systematically constructing five teach-

ing modules based on common core diseases in emergency and key skill dimensions. Each module selects typical clinical cases and clearly defines the focus of core competency cultivation, aiming to achieve stepwise training from single knowledge to comprehensive clinical competence through a virtual simulation environment (Table 1).

Table 1. Teaching modules for the construction of the emergency CT case library.

Module Category	Core Teaching Focus	Core Teaching Focus	Core Competency Cultivation Focus
Acute Neurovascular Emergencies	Quick and accurate imaging for time-sensitive diseases	Acute ischemic stroke; Cerebral hemorrhage; Subarachnoid hemorrhage	Quickly identify clinical indications and master the green channel process for stroke (referring to the standardized process established for the rapid diagnosis and treatment of acute stroke patients, which requires radiology technicians to complete the examination in an extremely short time); Optimization of multi-phase vascular perfusion scanning protocols; Identification of contraindications in emergency (such as renal insufficiency); Preliminary determination of critical values for major vascular occlusion and other life-threatening conditions (referring to abnormal findings discovered in imaging examinations that may immediately endanger the patient's life, such as active bleeding, brain herniation, aortic dissection, etc., which require the technician to report to the clinician immediately) signs.
Acute Chest Pain Emergencies	Differential diagnosis pathways for chest pain etiologies	Acute pulmonary embolism; Aortic dissection; Acute coronary syndrome	Understanding the imaging examination pathways for different chest pain etiologies; Master the electrocardiogram (ECG) gating technique or the chest pain triad scanning protocol (referring to a single CT enhanced scan used simultaneously to rule out pulmonary embolism, aortic dissection and coronary heart disease, with specific requirements for the scanning timing, contrast agent injection and ECG gating technique); Personalized optimization of contrast agent injection protocols; Identification of life-threatening imaging manifestations such as aortic dissection and pulmonary embolism.
Acute Abdominal Emergencies	Scanning strategies and sign recognition for abdominal emergencies	Gastrointestinal perforation; Intestinal obstruction; Rupture and hemorrhage of abdominal solid organs	Preparation before scanning (oral/rectal contrast agent application); Reasonable selection of plain scan and enhanced scan timing; Understanding the clinical value of multi-phase scanning; Alertness to key signs such as free gas, fluid level, and active bleeding.
Multiple Trauma	Rapid whole-body assessment of severe trauma	Multiple injuries caused by traffic accidents (requiring whole-body trauma CT screening)	Triage classification and scan priority judgment; Risk control of scanning for patients with unstable vital signs; Formulation and efficient execution of rapid whole-body scanning protocols; Awareness of rapid screening for active bleeding, organ contusion and laceration, and fractures.
Special and Critically Ill Patients	Ethical communication and emergency handling for special populations	Pediatric emergency; Acute abdomen in pregnant women; Agitated patients with impaired consciousness	Radiation protection for special populations (children, pregnant women); Special communication skills with families and clinicians; Simulation of cooperation process for sedation or restraint; Emergency plans for unexpected situations such as vomiting and cardiac arrest during scanning.

3.4. Technical Implementation and Key Elements

A complete virtual simulation case for emergency CT mainly consists of five core elements: three-dimensional virtual environment, virtual patient model, virtual equipment simulation, dynamic image generation engine, and intelligent evaluation and feedback system. These elements jointly build a highly realistic, safe, controllable, and repeatable training digital environment (**Table 2**).

Table 2. System composition of the emergency CT virtual simulation case.

Core Elements	Functional Description
Three-dimensional virtual environment	Builds realistic emergency department, CT examination room, and control room scenes, providing immersive spatial perception.
Virtual patient model	Simulates “digital patients” with dynamic vital signs, interactive clinical manifestations, and corresponding pathological image features.
Virtual equipment simulation	Highly simulates the CT operation console, supporting the setting and adjustment of various scanning parameters (tube voltage, milliamperere seconds, pitch, reconstruction algorithm, etc.).
Dynamic image generation engine	Generates CT image sequences in real time based on the condition and scanning parameters, presenting anatomical, pathological, and artifact image features, reflecting the influence of parameters.
Intelligent evaluation and feedback system	Automatically records, evaluates the operation process, parameter selection, image quality, and critical value recognition based on the rule base, and provides real-time feedback.

3.5. Example of the Rule Base of the Intelligent Assessment System

The rule base of the intelligent assessment system is jointly developed by clinical and educational experts, covering multiple dimensions such as process, technology, safety, and communication. Representative scoring items include: 1) Reasonableness of scanning parameters: For instance, for a routine adult brain scan, whether the tube voltage is within the range of 120 - 140 kV and whether the noise index exceeds the preset threshold. 2) Efficiency of scanning time: For stroke green channel cases, whether the total time from the patient’s “arrival” at the CT room to the completion of the scan is within the target time. 3) Safety checks and contraindication identification: The system records whether the student virtually inquires about the patient’s allergy history, renal function (such as creatinine value), and pregnancy status before the examination. Points are deducted for missing key items. Feedback methods include real-time prompts (such as popping up a prompt box when the set parameters significantly deviate from the norm) and post-task comprehensive reports (generating a detailed score sheet after the case ends, listing each item’s score, error points, and improvement suggestions). The assessment of critical value identification is judged by whether the student clicks and marks the key lesion (such as a large area of cerebral hemorrhage) within the specified time after browsing the images, and whether the system’s built-in communication tool simulates the sending of a report.

4. PBL Teaching Process Design and Implementation Based on Case Database

The construction of the case database is the foundation, but effectively integrating it into the PBL teaching process is the key to achieving teaching goals. It is recommended to implement the “double-loop” PBL teaching model, and the specific process is as follows:

4.1. Pre-Class Preparation Stage (Teacher-Led)

4.1.1. Case Selection and Problem Design

Teachers select matching cases from the case database based on the teaching objectives of the syllabus. Carefully design driving questions, such as: “As the on-duty technician, upon receiving a check request from a patient with sudden severe chest pain and breathing difficulties, how would you plan the subsequent work?”

4.1.2. Preparation of Learning Resources

Provide an index of background materials related to the case (such as clinical guidelines, sections of equipment manuals, and classic literature), but do not directly provide the answers.

4.1.3. Student Grouping and Role Assignment

Divide students into groups of 4 to 6, and within each group, students can take turns playing the roles of the main operator, assistant operator, communicator with the emergency doctor, and patient’s family member, etc., to promote multi-angle thinking.

4.2. In-Class Inquiry and Practice Stage (Student-Centered)

4.2.1. First Stage: Context Introduction and Problem Analysis (Online/Offline)

Each group enters the virtual case scenario through the terminal and gets the initial information of the “virtual patient” (age, gender, chief complaint, vital signs). Under the guidance of the PBL instructor, they conduct a brainstorming session around the driving question and list the problems that need to be solved: What disease might the patient have? What CT examination is most needed? What risks (allergy, renal function) need to be evaluated before the scan? What if the patient is agitated? What are the expected key imaging manifestations?

4.2.2. Phase Two: Autonomous Exploration and Knowledge Construction

Group members divide tasks and collaborate, using the provided resource package and independently searching for information to learn about the pathophysiology of related diseases, CT examination protocols, imaging manifestations, and precautions.

4.2.3. Phase Three: Virtual Simulation Practice and Decision-making

The group operates the virtual simulation system together, completing the entire process from patient reception to examination completion. Communication and

assessment: Engage in dialogue with virtual doctors, nurses, or family members to obtain more detailed medical history; conduct safety assessments on virtual patients. Plan formulation and operation: Set the scanning range, parameters, contrast agent injection plan, etc., on the virtual CT console; the system will provide real-time feedback on whether the parameters are reasonable. Image acquisition and initial judgment: After the scan is completed, the system generates images; the group needs to browse the images together, identify key signs, determine if the examination was successful, and whether additional scans are needed. Handling emergencies: The system presets emergency situations (such as patients vomiting during the scan or having an allergic reaction to the contrast agent), testing students' emergency response capabilities.

4.3. Phase Four: Group Summary and Presentation

Each group organizes the practice process, focusing on analyzing the basis for decision-making, gains and losses from operations, encountered difficulties and solutions, and prepares for presentation.

4.4. Post-Class Evaluation and Reflection Stage (Teacher-Student Joint Evaluation)

4.4.1. Multi-Dimensional Evaluation

Systematic Automatic Evaluation: Based on operation logs and image results, generate quantitative evaluation reports (such as operation standardization scores, image quality scores, and time efficiency scores). Peer Evaluation and Self-evaluation within Groups: Evaluate teamwork and problem-solving processes. Teacher Evaluation: Qualitatively assess students' clinical thinking and knowledge integration abilities based on group presentation performances and reflection reports.

4.4.2. In-Depth Reflection and Expansion

Teachers organize summary discussions to reveal the core knowledge chain behind the cases, compare different groups' solutions, and elevate the learning theme. Guide students to write reflection logs, connecting virtual experiences with future real clinical work.

5. Teaching Application

A controlled teaching experiment was conducted among the 2021-level undergraduate students majoring in Medical Imaging Technology. A total of 30 junior students who had completed the professional basic courses were included and randomly divided into an experimental class and a control class, with 15 students in each group. The experimental class adopted the "PBL integrated with virtual simulation case library" teaching mode, while the control class followed the traditional teaching mode (theoretical lectures, equipment visits, film reading, and operation demonstrations). The teaching intervention lasted for 8 weeks (2 class hours per week), covering the four core modules of emergency CT.

The effect evaluation was based on systematic scoring and blind assessment by

teachers: 1) The ability to formulate scanning protocols (out of 100 points): The entire process from patient reception to parameter setting was automatically evaluated by the virtual simulation system, covering dimensions such as indication judgment (10 points), safety check (15 points), scanning range (20 points), parameter setting (30 points), timeliness (15 points), and communication (10 points); 2) The ability to analyze image quality control (out of 100 points): Double-blind teachers scored students' performance in analyzing preset problem images based on a unified scale (50 points for the accuracy of image problem identification, 30 points for the rationality of cause analysis, and 20 points for the feasibility of improvement suggestions).

The results showed that the experimental class scored significantly higher in the ability to formulate scanning protocols (82.4 points \pm 6.7 points) than the control class (70.1 points \pm 8.3 points) ($t = 6.52$, $P < 0.001$, 95% CI = [8.4, 16.2]); the ability to analyze image quality control (85.6 points \pm 5.9 points) was also significantly higher than that of the control class (73.8 points \pm 7.5 points) ($t = 6.90$, $P < 0.001$, 95% CI = [8.3, 15.3]). The questionnaire survey indicated that 87% of the students in the experimental class believed that this mode enhanced their confidence in clinical decision-making and systematic working ability, and 93% of the students were satisfied with the teaching mode. The core advantage of this mode lies in achieving "zero-risk" training for "high-risk" emergency skills, breaking the linear fragmentation of traditional teaching, promoting the integration of knowledge units into complete work processes, and facilitating precise teaching improvement through immediate and process-based evaluation feedback. At the same time, it effectively cultivates students' abilities of autonomous learning, collaborative learning, and reflective learning.

6. Discussion

Against the background of the digital transformation of medical education and the construction of new medical science, the particularity and urgency of emergency imaging teaching have become increasingly prominent. The construction and application of the "PBL-based virtual simulation emergency CT case library" has emerged as an innovative and promising teaching reform path. This model, through technological empowerment, creatively addresses the core challenges of "high risk, difficult reproduction, and lack of integration" in clinical practice teaching, achieving a deep integration of the inquiry-based advantages of PBL and the immersive and safe advantages of virtual simulation, thus building a "bridge of ability transformation" for students from theory to clinical practice. It not only imparts static knowledge and operational skills but also systematically cultivates students' comprehensive professional qualities such as clinical thinking, emergency decision-making, and teamwork in complex, dynamic, and high-pressure emergency environments.

However, this model still faces multiple challenges in practical promotion: high construction costs and collaboration complexity, with the development of high-

quality case libraries relying on in-depth collaboration among multiple disciplines including medicine, education, and technology, requiring significant initial investment; significant demands for teachers' role transformation, with teachers needing to shift from knowledge transmitters to learning guides, scenario designers, and process evaluators, urgently requiring systematic teacher development and training support; continuous calibration of technology application and teaching objectives, with the need to be vigilant against overemphasizing technological presentation and deviating from the core of ability-based education, ensuring that technology serves teaching effectiveness. The research also has certain limitations: Firstly, there are fidelity limitations in the physical haptic feedback of the virtual simulation environment and the emotional complexity of communicating with real patients. Secondly, the initial teaching experiments may have novelty or Hawthorne effects. Most importantly, the degree to which skills acquired in the virtual environment can be transferred to real clinical scenarios still needs further verification. To alleviate these limitations, future research plans include: 1) Developing hybrid training that combines with high-fidelity physical simulators (such as manikins); 2) Using the Objective Structured Clinical Examination (OSCE) format to set up multi-station assessments with standardized patients to more comprehensively evaluate students' comprehensive abilities; 3) Tracking students who participated in the experiments to compare their actual performance in subsequent clinical internships (especially in the emergency CT position) to assess the long-term retention and transfer effects of skills.

Looking ahead, this model can be further deepened in the following aspects: integrating artificial intelligence to achieve personalized learning and the cultivation of intelligent collaborative capabilities, using virtual reality/augmented reality to build cross-regional immersive collaborative training scenarios, promoting hybrid teaching through the integration of real hospital data and high-fidelity simulators, and relying on open and shared industry platforms to facilitate the large-scale popularization and continuous evolution of teaching resources.

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Conflicts of Interest

The authors declare no conflicts of interest.

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