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Construction and Practical Application of an Artificial Intelligence-Based Standardized Patient Teaching Model in Surgical Clinical Clerkship

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Abstract: *Objective:* To address the insufficient integration of theory and practice in surgical clinical clerkship teaching, the limited availability of authentic clinical cases, and the limitations of traditional standardized patients (SPs) in terms of consistency and organizational cost, this study aimed to develop an artificial intelligence-based standardized patient (AI-SP) teaching framework grounded in structured clinical case data. Lumbar disc herniation was used as a representative condition for application and exploratory implementation. *Methods:* An exploratory teaching application design was adopted. Based on the learning objectives of the lumbar disc herniation chapter in standard surgery textbooks, a layered AI-SP system was developed, comprising a case data layer, a clinical rules and teaching logic layer, and an AI interaction layer. Clinical case data were derived from a single-center spine surgery practice and were de-identified and structured into teaching-oriented data units. Diagnostic and therapeutic principles from textbooks, together with expert consensus and clinical guidelines, were abstracted into rule constraints and scenario evolution logic. The interaction layer employed a large language model to support multi-turn dialogue, with standardization ensured through role restriction, rule-based control, and consistency validation. The system was embedded into three stages of clerkship teaching—pre-clerkship preparation, in-clerkship guidance, and post-clerkship consolidation—and representative interaction workflows were developed. *Results:* A layered AI-SP architecture and information flow model tailored for surgical clinical clerkship teaching was established. Under predefined rule constraints, the system was able to generate stable patient narratives consistent with textbook content and clinical reasoning, enabling reproducible and controllable standardized teaching scenarios. An exploratory application suggested that the AI-SP facilitated the formation of a more structured disease understanding before students entered real clinical settings, improved the consistency and focus of clerkship discussions, and supported repeated practice under conditions of limited clinical resources. Quantitative evaluation of learning outcomes was not conducted in this study. *Conclusion:* The AI-SP framework, developed using artificial intelligence and structured clinical case data, may serve as an auxiliary tool for surgical clinical clerkship teaching by providing a controlled and standardized interactive training environment without replacing students' clinical judgment. Future studies should incorporate multicenter case data and employ controlled designs with quantitative outcome measures to systematically evaluate the educational effectiveness.

Keywords: Artificial intelligence; Standardized patient; Surgical education; Clinical clerkship; Large language model

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1. Introduction

Surgery is a discipline that relies heavily on clinical practice. Its educational objectives extend beyond the transmission of theoretical knowledge to the development of clinical thinking skills, including diagnostic reasoning and therapeutic decision-making. However, in routine teaching practice, limitations related to the availability of authentic clinical cases, the distribution of disease types, and the organization of teaching activities often restrict students' opportunities to engage in systematic and repeated clinical reasoning during the clerkship stage. As a result, a noticeable gap between theory and practice persists in surgical education [1].

Standardized patients (SPs) have long been recognized as an important educational tool in medical education, contributing to enhanced realism and interactivity in teaching scenarios [2]. In surgical education, however, traditional SPs face inherent limitations. Their capacity to simulate complex diagnostic processes, imaging-dependent information, and dynamic disease progression is restricted, while issues related to performance consistency and organizational cost hinder their sustained and routine implementation [3,4].

With advances in artificial intelligence, virtual patients based on large language models have introduced new possibilities for creating stable and reproducible educational scenarios [5,6]. By integrating artificial intelligence with authentic clinical case data and established surgical diagnostic and therapeutic rules, it may be possible to improve interaction flexibility while maintaining educational standardization, thereby providing a more controlled training environment for surgical education.

Spine surgery represents a core component of surgical training, characterized by complete diagnostic pathways and clearly defined decision-making nodes, making it particularly suitable for the cultivation of surgical clinical reasoning skills. Nevertheless, teaching in this subspecialty is similarly constrained by limited case accessibility and restricted student participation [7]. Accordingly, the present study uses lumbar disc herniation as a representative example to develop and explore an artificial intelligence-based standardized patient (AI-SP) teaching model, with the aim of providing a methodological reference for surgical clinical clerkship education.

2. Methods

2.1. Study design and focus

This study adopted an exploratory teaching application design to address the practical challenge of insufficient integration between theory and practice in surgical education. Given that the use of artificial intelligence in medical teaching remains at an early exploratory stage, the study did not attempt to encompass the entire surgical curriculum. Instead, a specific chapter with clearly defined learning objectives and a relatively mature teaching pathway was selected as the entry point to ensure feasibility and methodological relevance [8].

Based on this design rationale, the lumbar disc herniation chapter in standard surgery textbooks was chosen as the study focus. This topic is characterized by well-defined clinical manifestations, diagnostic reasoning processes, and treatment principles, and it covers key components of surgical education, including symptom analysis, physical examination, imaging-based assessment, and therapeutic decision-making. Using this teaching unit, the study explored the construction of an artificial intelligence–based standardized patient and its application in clinical clerkship teaching, with particular attention to feasibility, standardization, and reproducibility, thereby providing a methodological reference for extension to other surgical conditions and teaching contexts.

2.2. Overall architecture of the AI-based standardized patient system

Based on the teaching content of lumbar disc herniation and the requirements for standardized patient–assisted instruction, an AI-SP system was developed for use in surgical clinical clerkship settings. The system was designed with a teaching-oriented focus, aiming to support the presentation of diagnostic reasoning and therapeutic decision-making processes while emphasizing operational feasibility and reproducibility.

The AI-SP system adopted a layered architecture consisting of three components: a case data layer, a clinical rules and teaching logic layer, and an AI interaction layer [9]. These components function independently while operating in coordination to support the generation and application of the AI-SP in lumbar disc herniation clerkship teaching.

The case data layer was constructed from relevant clinical cases. Through de-identification and structured processing, information related to medical history, symptoms and signs, physical examination findings, textual descriptions of imaging features, and treatment-related information was transformed into standardized data units, providing a stable data foundation for AI-SP development [10].

The clinical rules and teaching logic layer was established based on textbook diagnostic criteria and treatment principles, supplemented by expert consensus statements and clinical practice guidelines. This layer constrains the scope of information presentation, disease progression pathways, and instructional guidance to ensure consistency and reproducibility of AI-SP performance across different teaching sessions.

The AI interaction layer was built on a large language model to enable natural language interaction between the standardized patient and students. Under predefined rule constraints, the system generates patient responses that simulate symptom expression and clinical encounters, without directly providing diagnostic or therapeutic conclusions, thereby guiding students to engage in disease analysis and clinical reasoning training [11].

2.3. Case data sources and structured processing

The construction of the AI-SP was based on the lumbar disc herniation chapter in surgery textbooks, with clinical case data derived from a single-center spine surgery practice. All cases underwent strict de-identification prior to inclusion, and only core clinical information relevant to teaching purposes was retained. No analyses of clinical outcomes or patient prognoses were performed [12].

Case selection was guided by textbook teaching requirements, prioritizing cases with typical clinical presentations, diagnostic pathways, and treatment decision processes, while also incorporating variability in symptom presentation and disease severity to meet the needs of disease recognition and clinical reasoning training during the clerkship stage. Emphasis was placed on pedagogical representativeness and completeness rather than sample size or statistical considerations.

To facilitate system utilization, clinical case information was structured by decomposing traditional medical records into predefined modules, including basic patient information, chief complaints and symptom characteristics, physical examination findings, textual descriptions of imaging features, diagnostic conclusions, and treatment-related information. Standardized and constrained descriptions were applied to reduce ambiguity and enhance data consistency and instructional clarity [13].

Imaging information was not presented as original imaging files but rather as textual descriptions commonly used in clinical teaching, highlighting responsible segments, herniation types, and patterns of neural structure compression. Treatment-related information was used solely to support internal logic and disease progression design and was not directly disclosed to students, in order to avoid replacing their clinical judgment [14].

Through these processes, traditional clinical records were transformed into teaching-oriented data units that could be stably accessed by the system, thereby providing a foundation for AI-SP generation and subsequent rule-based logic design.

2.4. Clinical decision rules and teaching logic design

The design of clinical decision rules and teaching logic is critical to ensuring both instructional standardization and clinical validity. In this study, diagnostic and therapeutic principles for lumbar disc herniation outlined in standard textbooks served as the primary framework, supplemented by relevant expert consensus statements and clinical practice guidelines [15,16]. The implicit clinical reasoning pathways involved in diagnosis and treatment were abstracted and embedded into the system in the form of explicit rules to regulate information presentation and disease evolution.

With respect to diagnostic logic, the system restricts the scope of patient responses based on textbook diagnostic criteria. The standardized patient responds only with information related to chief complaints, symptom distribution, physical examination findings, and textual imaging descriptions, without providing diagnostic conclusions or suggestive judgments, thereby guiding students to independently construct diagnostic reasoning.

Regarding treatment logic, the system is grounded in textbook treatment principles and incorporates guideline-based recommendations on surgical indications, conservative management, and minimally invasive treatment options. When students propose different management strategies, the standardized patient presents corresponding disease responses or contextual changes within rule-defined limits, without evaluating the correctness of the students' decisions.

In terms of disease progression and instructional guidance, the system triggers different contextual feedback based on students' questions and decisions. This approach supports discussion and reasoning extension during clerkship teaching and emphasizes understanding diagnostic and therapeutic logic through scenario evolution rather than outcome-oriented evaluation.

2.5. AI interaction and standardization control mechanisms

Within the AI-SP system, the artificial intelligence module is responsible for natural language interaction between the standardized patient and students. Its role is explicitly restricted to that of a "patient," simulating subjective experiences and objective clinical manifestations without assuming responsibilities for diagnosis, treatment decision-making, or instructional evaluation, thereby ensuring that students remain the central agents in clinical reasoning training [17].

The system supports multi-turn dialogue through a large language model, with patient responses jointly constrained by structured case data and the clinical rules and teaching logic layer. This dual constraint mechanism ensures consistency in symptom description, clinical context, and encounter responses, thereby reducing the risk of content deviation or logical inconsistency associated with unconstrained text generation [18].

In terms of feedback mechanisms, the system advances the instructional process through scenario-based feedback. Changes in patient status—such as pain intensity, functional limitation, or impact on daily activities—reflect disease progression under different contexts and prompt students to further analyze and refine their diagnostic and therapeutic reasoning, without providing explicit correctness judgments.

For standardization control, generated content is managed through a combination of rule constraints and output validation procedures [19]. This approach restricts medical judgments beyond the patient's role and reduces variability in AI-SP performance across different teaching sessions, thereby ensuring stability and reproducibility of instructional scenarios.

2.6. Teaching application scenarios and implementation workflow

The AI-SP was primarily applied during the clinical clerkship stage of the lumbar disc herniation module in the surgery curriculum, serving as an auxiliary tool to bridge classroom-based theoretical learning and real-world clinical practice [20].

During the pre-clerkship preparation phase, instructors organized student interaction with the AI-SP to familiarize learners with common chief complaints, symptom distributions, key physical examination findings, and imaging interpretation approaches, thereby enhancing the focus and relevance of subsequent clinical exposure [21].

During the clerkship implementation phase, the AI-SP served as a supplement to real patient resources by providing a unified teaching scenario and representative case presentations. Under instructor guidance, students conducted history taking, problem analysis, and diagnostic reasoning discussions based on the same standardized patient, reducing instructional imbalance caused by limited case availability or heterogeneous disease presentations [22].

In the post-clerkship consolidation phase, instructors integrated observations from real clinical settings with renewed AI-SP interaction to review and reinforce diagnostic and treatment principles. By comparing simulated scenarios with real patient encounters, students were encouraged to deepen their understanding of the relationship between textbook knowledge and clinical practice.

This study primarily focused on the feasibility and instructional adaptability of the AI-SP in surgical clinical clerkship teaching. Quantitative evaluation of learning outcomes was not conducted, and systematic assessment through multicenter studies will be pursued in future research.

3. Application exploration and illustrative examples

3.1. Exploration of the application process in surgical clinical clerkship

Based on the previously described AI-SP construction approach, an exploratory application was conducted during the clinical clerkship phase of the lumbar disc herniation module in the surgery curriculum. The AI-SP was positioned as an auxiliary teaching tool and integrated into the existing clerkship workflow to support students in developing disease understanding and clinical reasoning both before and after entering real clinical settings [20].

In practice, the clerkship teaching process comprises three stages: pre-clerkship preparation, in-clerkship guidance, and post-clerkship consolidation. Instructors selected appropriate AI-SP cases according to instructional objectives and guided students to focus on key learning components, including chief complaint elicitation, symptom analysis, essential physical examination findings, and imaging-based assessment. By introducing a unified standardized patient scenario, students were able to engage in analysis and discussion from a relatively consistent starting point, thereby reducing the influence of variability among real clinical cases on the teaching process [22].

3.2. Illustrative example of lumbar disc herniation clerkship teaching (Table 1)

In clerkship teaching related to lumbar disc herniation, instructors used the AI-SP as a unified teaching subject to organize problem-oriented learning activities. Students typically participated in small groups and, under instructor guidance, worked within the same standardized patient scenario to sequentially complete key steps of history-taking, symptom analysis, and discussion of diagnostic and therapeutic reasoning.

At the initial stage of the clerkship session, instructors guided students to begin systematic questioning based on the patient's chief complaint. Through interaction with the AI-SP, students gradually obtained disease-related information. During this process, instructors focused on the completeness and logical structure of students' questions and provided guiding prompts when necessary, rather than directly offering standard answers, in order to promote active thinking and information integration.

During the discussion stage, students analyzed the collected information with reference to diagnostic reasoning and treatment principles for lumbar disc herniation. Different students or groups could arrive at distinct analytical pathways within the same standardized patient scenario. Instructors then guided students to compare the rationale and completeness of these approaches, thereby deepening their understanding of textbook content and clinical reasoning processes.

Table 1. Examples of AI-SP–based interaction

Interaction stage	Key student actions	Example of AI-SP contextual feedback	Instructional focus
History taking	Inquiry about pain distribution and activity-related changes	"I usually feel a dull ache in my lower back. After activity, the pain radiates from the right buttock to the posterolateral aspect of the lower leg and is slightly relieved by rest."	Guiding students to recognize radicular pain patterns and their relationship to physical activity in lumbar disc herniation
Physical examination	Inquiry about neural tension tests and sensory changes	"When my right leg was raised during the examination, I felt a marked pulling pain along the outer side of my lower leg, accompanied by numbness."	Helping students understand the clinical significance of nerve root compression–related signs and sensory abnormalities

In the post-clerkship summary stage, instructors synthesized key teaching points using the standardized patient scenario and guided students to compare their analytical processes in the simulated setting with observations from real ward-based clerkship experiences. This approach aimed to enhance the focus and continuity of clinical clerkship teaching.

3.3. Teaching observations during application exploration

Teaching observations during the application process suggested that the AI-SP facilitated the development of a relatively structured disease understanding before students entered real clinical environments, enabling them to focus more effectively on key clinical information during clerkship activities [22]. The use of a unified standardized patient scenario also facilitated the organization of clerkship discussions by instructors, shifting instructional emphasis from differences among cases to analysis and comparison of students' diagnostic and therapeutic reasoning [22].

In addition, as a reusable teaching resource, the AI-SP enabled repeated practice opportunities under conditions of limited clinical resources, partially mitigating the impact of restricted case availability and uneven disease distribution on clerkship teaching.

It should be noted that the present application exploration primarily focused on the feasibility and instructional adaptability of the AI-SP in surgical clinical clerkship teaching. Systematic quantitative evaluation of student learning outcomes was not conducted. Controlled studies and multicenter validation of educational effectiveness will be pursued in future research [1].

4. Discussion

The clinical clerkship phase represents a critical transition for medical students from classroom-based learning to real clinical practice. In routine teaching, however, this stage is often constrained by limited case availability, uneven distribution of disease types, and insufficient opportunities for direct student participation. These practical limitations can weaken students' ability to engage in systematic disease analysis and clinical reasoning training. By simulating representative clinical scenarios, the AI-SP provides a reusable "virtual patient," partially compensating for the restricted availability of real patient resources in clinical clerkship teaching [21]. The integration of AI-SP into clerkship activities helps establish relatively stable and controllable instructional contexts, allowing students to repeatedly practice disease analysis within a consistent case framework and thereby supporting the development of surgical clinical reasoning skills.

Compared with traditional standardized patients, AI-SP demonstrates advantages in performance consistency, reusability, and instructional organization costs [4]. Moreover, in contrast to static virtual cases or text-based case descriptions, the interactive nature of AI-SP more effectively encourages students to actively ask questions, integrate information, and engage in analytical thinking [8]. This interaction-centered instructional approach facilitates a shift from passive information reception to active construction of diagnostic and therapeutic reasoning, which is well aligned with the objectives of surgical clerkship education.

With respect to instructional content design, this study adopted the lumbar disc herniation chapter of standard surgery textbooks as the primary teaching framework and extended it by incorporating relevant expert consensus statements and clinical practice guidelines. This approach—grounded in textbooks and supplemented by clinical practice—ensures instructional standardization while also addressing real-world clinical needs [15]. By integrating textbook-based diagnostic frameworks with authentic clinical decision-making contexts, the AI-SP supports students in gradually understanding the translation of theoretical knowledge into clinical application during the clerkship stage [1], thereby reducing the perceived disconnect between theory and practice.

Clearly defining the role boundaries of artificial intelligence is particularly important in AI-assisted teaching. In the present study, artificial intelligence was strictly confined to the role of a "patient," simulating subjective experiences and objective clinical manifestations without assuming responsibilities for diagnosis, treatment decision-making, or instructional evaluation. This design prevents artificial intelligence from replacing students' clinical reasoning processes and ensures that learning activities remain student-centered [17]. In addition, the incorporation of rule-based constraints and standardization control mechanisms contributed to stable and consistent system performance across different teaching sessions [18], offering a feasible pathway for the safe and regulated application of artificial intelligence in medical education.

Several limitations of this study should be acknowledged. First, the clinical cases were derived from a single-center practice, which may limit the representativeness of the case spectrum. Second, the study focused primarily on the construction and exploratory application of the teaching method, and systematic quantitative evaluation of student learning outcomes was not conducted; thus, the conclusions were mainly based on teaching observations [1]. Furthermore, lumbar disc herniation was used as the sole exemplar condition, and other surgical disease categories were not included. These limitations indicate the need for future studies to incorporate multicenter case data, expand the range of surgical conditions, and apply controlled study designs to more comprehensively evaluate the educational effectiveness of AI-SP across different teaching stages [18].

Looking ahead, AI-based standardized patient systems may be extended to additional surgical disease modules and progressively integrated into higher-level teaching stages, such as clinical internships [22]. Moreover, comparative analyses of learning outcomes under different instructional models, supported by multicenter educational practice, would facilitate a more comprehensive assessment of the practical educational value of this approach. As artificial intelligence technologies and medical education paradigms continue to evolve, further exploration is warranted to enhance the interaction realism and instructional adaptability of AI-SP while maintaining educational standardization and safety [19].

5. Conclusion

This study developed and explored an AI-SP teaching model in response to the needs of surgical clinical clerkship education, using lumbar disc herniation as a representative example to examine its feasibility and instructional applicability. The findings indicate that, under predefined rule constraints, the AI-SP can consistently present teaching scenarios aligned with textbook content and clinical logic, helping to establish a unified instructional starting point and support structured clinical reasoning training among students. Without replacing students' clinical judgment, this approach provides a controllable and reproducible auxiliary tool for surgical clerkship teaching. Future studies should employ multicenter and controlled designs to systematically evaluate its educational effectiveness and further expand its application to other surgical conditions and teaching stages.

Disclosure statement

The authors declare no conflict of interest.

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