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Integration of 3D printing and case-based learning in clinical practice for the treatment of developmental dysplasia of the hip

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Abstract

Background Case-based learning (CBL) utilizing three-dimensional (3D) printed hip joint models is a problem-solving teaching method that combines the tactile and visual advantages of 3D-printed models with CBL. This study aims to investigate the impact of integrating 3D printing with CBL on learning developmental dysplasia of the hip (DDH).

Methods We conducted a prospective study from 2022 to 2023, including 120 fourth-year clinical medical students at Xuzhou Medical University. Students were randomly allocated into two groups of 60 participants each. The CBL group received conventional CBL teaching methods, while the 3D + CBL group utilized 3D-printed models in conjunction with CBL. Post-teaching, we analyzed and compared the theoretical and practical achievements of both groups. A questionnaire was designed to assess the impact of the educational approach on orthopedic surgery learning.

Results The theory scores of the CBL group (62.88 ± 7.98) and 3D + CBL group (66.35 ± 8.85) were significantly different ($t = 2.254$, $P = 0.026$); the practical skills scores of the CBL group (57.40 ± 8.80) and 3D + CBL group (63.42 ± 11.14) were significantly different ($t = 3.283$, $P = 0.001$). The questionnaire results showed that the 3D + CBL group was greater than the CBL group in terms of hip fundamentals, ability to diagnose cases and plan treatments, interesting teaching content, willingness to communicate with the instructor and satisfaction.

Conclusions The integration of 3D printing with case-based learning has yielded positive outcomes in teaching DDH, providing valuable insights into the use of 3D-printed orthopedic models in clinical education.

Keywords 3D-printed model, Case-based learning, Orthopedic education, Developmental dysplasia of the hip

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Introduction

Developmental dysplasia of the hip (DDH) is a condition characterised by abnormal development of the hip joint, including dysplasia of the femoral head and acetabulum, subluxation of the hip joint, and dislocation of the hip joint [1, 2]. Surgical intervention is a viable treatment option, but the complexity of surgery and the variability of hip joint anatomy pose challenges for both teaching and learning. Knowledge of the three-dimensional (3D) structure of the hip joint requires medical students to have certain clinical practice experience and spatial construction ability, while the traditional teaching of hip diseases mainly relies on textbooks, courseware and cadaveric specimens, which have limitations in understanding the pathological structure of the hip joint and surgical procedures [3–5]. 3D-printed models visually represent the local anatomical structure of the lesion and have obvious advantages in diagnosing complex diseases and facilitating simulated surgeries [6–8]. An increasing number of educators are turning to emerging technologies such as 3D printing to bridge the gap between theory and practice in medical education [5, 8, 9].

Case-based learning (CBL) is a pedagogical approach that emphasises the practical application of knowledge in a real-world context [10]. It entails presenting students with clinical cases and guiding them through the problem-solving process, thereby fostering critical thinking and problem-solving skills as well as promoting long-term retention of knowledge [11, 12]. 3D printing and CBL have been widely used in orthopedic teaching to promote students' understanding of orthopedic surgery and to provide new ideas for orthopedic clinical teaching [13–15]. The integration of 3D printing technology and CBL methods has enabled the creation of accurate 3D joint models and the simulation of surgical procedures, enhancing the understanding and visualisation of pathological structures and surgical procedures in DDH patients.

The aim of this study was to investigate the impact of the integration of 3D printing and CBL in learning about DDH and to provide insights into future teaching practices. We hypothesise that the integration of 3D-printed models with case-based learning in DDH will have positive effects on grounded theory and practical skills, increasing student interest and satisfaction.

Methods

Research design

We selected 120 fourth-year undergraduate university students enrolled in clinical programmes from January 2022 to March 2023 for the study. The students were randomly divided into a CBL group and a CBL+3D group by a random number table with 60 students in each group. Both groups received a 6-month orthopaedic course.

The 3D+CBL group received instructions on 3D-printed models combined with case-based learning (CBL), and the CBL group received only traditional CBL instruction. The content of knowledge covered in the instructions was identical in the 3D+CBL and CBL groups. All students signed an informed consent form prior to participation, making it clear that their participation was voluntary and that they could withdraw from the study at any time. We anonymized all participants' personal information, using separate study numbers instead of any identifiable information to ensure maximum protection of patient privacy. This study was approved by the Ethics Committee of the Affiliated Hospital of Xuzhou Medical University (XYFY2023-KL146-01) and was exempt from review.

Sample size calculation

Sample size calculations were performed using G*Power software (version 3.1.9.6, Dusseldorf, Germany). The determination of the sample size relied on the main outcome indicator of the study: students' understanding of orthopaedic surgery. A statistical power of 80% and a two-tailed $\alpha = 0.05$ were assumed. The necessary sample size was estimated to be 50 students per group, based on an effect size of 0.5 (Cohen's *d*) derived from the data reported by Zhao et al. [16]. Considering a potential dropout rate of 20%, a total of 120 students will be recruited.

Teaching methods

A database of adult patients with hip dysplasia was established. Data on patients who underwent total hip arthroplasty for DDH in our department between 2020 and 2021 were collected. The patients had good compliance and could be followed up on time. Among them, there were two cases of Crowe type IV and one case of type III [17]. Patient data included the general condition, routine preoperative blood tests, CT imaging of the hip joint, diagnosis, treatment plan, diagnostic and therapeutic process, intraoperative photographs and postoperative X-rays. All typical cases were collected with the informed consent of the patients.

A 3D model of the hip joint was created. Preoperative images of the hip joint were imported into the 3D imaging software Mimics Research 21.0 (Materialise, Belgium), Geomagic Studio 2017 (Geomagic, USA) and Solidworks 2018 (Dassault Systemes, USA) in DICOM file format. The preoperative 3D model of the hip joint was built in an orderly manner by combining and utilising the functions of the different modules in the software. On the basis of 3D reconstruction, anatomical measurements, prosthesis design and printing can be performed (Fig. 1 and Figs. 2).

Group and implement teaching. Each group was divided into 6 subgroups of 10 participants, and the class

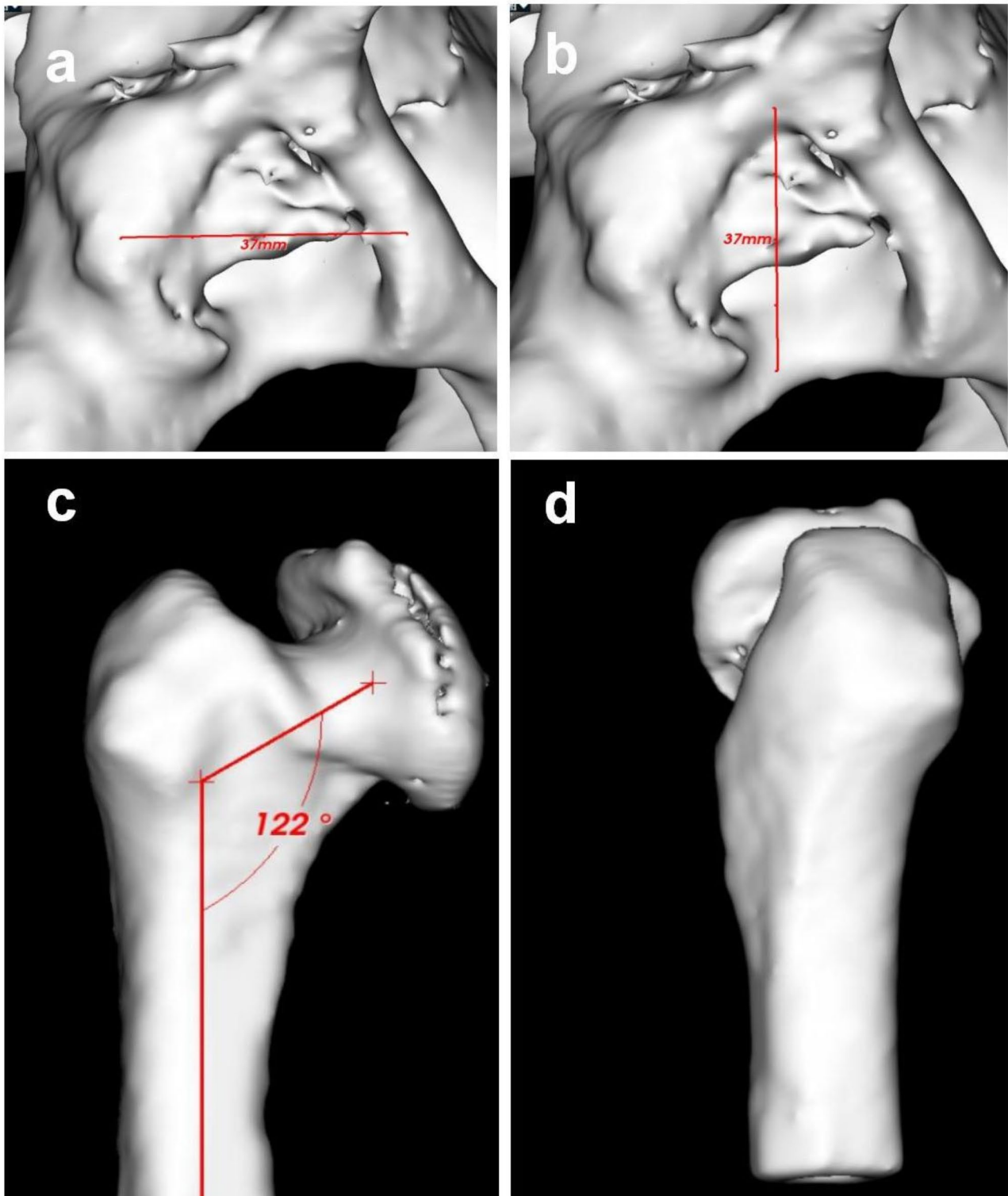


Fig. 1 Anatomical measurements and prosthesis design on 3D models. Figure legends: **a** and **b**. Measurement of transverse and upper and lower acetabular diameters; **c** and **d**. Frontal and lateral views of the femur and measurement of the femoral neck stem angle

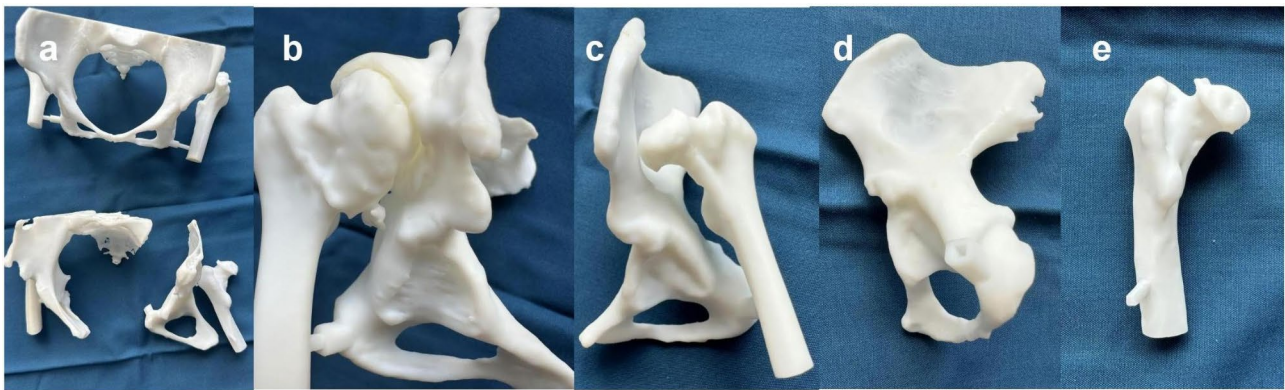


Fig. 2 3D printed model of DDH patients. Figure legends: **a**, Overall view of the 3D printed model of 2 patients with DDH **b**, 3D printed right hip joint of DDH patient; **c**, **d** printing left hip joint of DDH patient; **d**, DDH patient left acetabulum **e**, The left femur portion of the DDH patient contained the femoral head

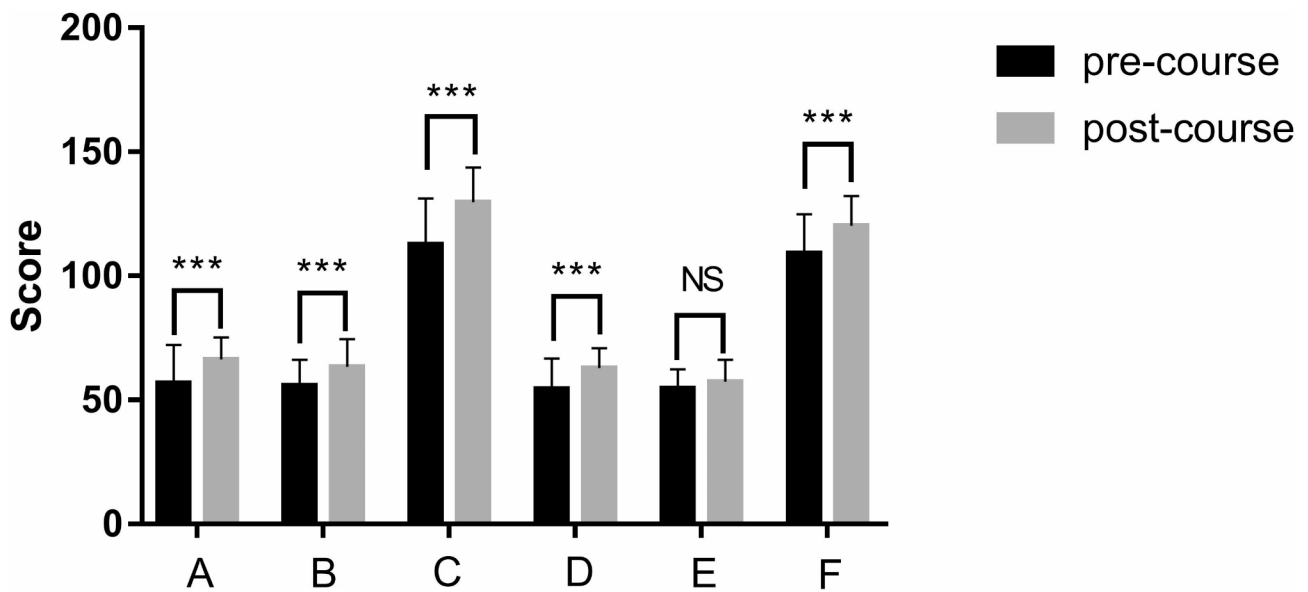


Fig. 3 Comparison of pre- and postclass scores between the CBL + 3D group and CBL group. Figure legends: **A&D**, **B&E** and **C&F** show comparisons of the theoretical, practical, and total scores of the CBL + 3D group and the CBL group before and after class, respectively. *** indicates $p < 0.001$

was scheduled for 4 class hours. The lecturers were led by two senior orthopedic surgeons (attending physicians for 5 years) and used the same CBL teaching cases and lectures. The focus of the course was on the anatomy and pathology of DDH and options for surgical treatment. Prior to the lesson, subjects in both groups were allowed to watch instructional videos on hip anatomy and DDH surgery and to prepare for the lesson. The scenario introduced a case of adult DDH for group discussion, and only a 3D-printed model of this patient in the 3D+CBL group and a brief description were provided. Students in both groups will work in groups to search for information and discuss the development of a treatment plan based on the patient’s history, specialist examination and ancillary tests. Afterwards, the students will design a CBL case based on the surgical procedure of the target orthopedic

surgery. Students will be divided into groups, and each group will be given a new case for DDH. They will need to analyse and discuss the case, develop a diagnosis and treatment plan, and present their results to the other members and the lecturers. During the discussion, students in the 3D+CBL group still received a 3D-printed model of the patient. At the end of the discussion, the lecturers commented on the results of the students’ discussions in each group, provided detailed summaries and answers to common and controversial questions, and finally emphasised the importance of deepening the students’ practical mastery of the knowledge related to the anatomy, pathology and surgical treatment of DDH.

Table 1 The basic characteristics of all the participants

Item	CBL group	3D+CBL group	Statistics	P value
Age	21.97±0.66	22.03±0.88	T=0.468	0.641
Gender			$\chi^2=0.556$	0.456
Male	26	22		
Female	34	38		

Evaluating teaching effectiveness

The primary outcome measure was the improvement in knowledge scores between the pretest and posttest. Prior to the start of the course, both groups of students were asked to complete the same test papers and single-choice and multiple-choice questions before the course. At the end, the teacher assessed the students' theoretical and practical performance and designed a questionnaire to evaluate the effectiveness of the teaching. The theoretical knowledge assessment included single-choice questions, multiple-choice questions, short-answer questions, and case analysis questions involving basic knowledge points related to hip dysplasia, diagnosis, and surgical methods, totaling 100 points. The practical assessment included history taking, medical record writing, imaging reading and choosing the surgical plan, with a total of 100 points.

At the end of the course, the two groups of students were given the same questionnaire for investigation. The questionnaire consists of 5 parts, and five aspects were scored: mastery of basic hip joint knowledge, ability to diagnose cases and formulate treatment plans, interesting teaching content, willingness to communicate with teachers, and teaching satisfaction. Students were asked to answer the questions based on these items with a total possible score of 10 and a minimum possible score of 2. Higher scores indicate higher student satisfaction. The secondary outcome measures will be surgical skill scores and surgical outcomes.

Statistical analyses

All the statistical analyses were performed using the statistical software SPSS version 26.0 (IBM Corp, Armonk, NY, USA). Independent samples t tests were used to compare continuous variables between two groups. The data are expressed as the mean and standard deviation (SD). The chi-square test was used for discontinuous variables. Differences with $P < 0.05$ were considered to indicate statistical significance.

Results

A total of 120 students were included in the experiment. The experimental group included 22 males and 38 females aged between 21 and 23 years, with an average age of 22.03 ± 0.88 years. The control group consisted of 26 males and 34 females aged 21 to 23 years, with a mean age of 21.97 ± 0.66 years; all the students were trainees. There was no significant difference in age ($t = 0.468$,

Table 2 Comparison of the pre-course and post-course tests between the two groups

Item	CBL group	3D+CBL group	T value	P value
Total pre-course score	109.32±15.54	112.75±18.58	1.098	0.275
Pre-course Theoretical knowledge score	54.53±12.20	56.88±15.38	0.927	0.356
Pre-course Practical skill score	54.78±7.67	55.87±10.36	0.651	0.516
Total post-course score	120.18±12.01	129.72±14.02	4.001	<0.001
Post-course Theoretical knowledge score	62.88±7.98	66.35±8.85	2.254	0.026
Post-course Practical skill score	57.40±8.80	63.42±11.14	3.283	0.001

$P = 0.641$) or gender ($\chi^2 = 0.556$, $P = 0.456$) between the two groups (Table 1).

Theoretical and practical performance

There was no significant difference in the performance of the two groups of students on the precourse test. The results of the postcourse assessment showed that the participants in the 3D+CBL group performed better than did those in the CBL group. The theory scores of the CBL group (62.88 ± 7.98) and 3D+CBL group (66.35 ± 8.85) were significantly different ($t = 2.254$, $P = 0.026$); the practical skills scores of the CBL group (57.40 ± 8.80) and 3D+CBL group (63.42 ± 11.14) were significantly different ($t = 3.283$, $P = 0.001$); and the total scores of the CBL group (120.18 ± 12.01) and 3D+CBL group (129.72 ± 14.02) were significantly different ($t = 4.001$, $P < 0.001$) (Table 2). In addition, in the comparison of theory scores and total scores before and after the course, the scores of students in both groups improved, and the difference was statistically significant. However, in the practical skills test, there was no difference in the scores of the two tests in the CBL group (Fig. 3).

Questionnaire

After teaching, a total of 120 questionnaires were distributed to the students, and the effective recovery rate was 100%. The results showed that the 3D+CBL group was greater than the CBL group in terms of hip fundamentals, ability to diagnose cases and plan treatments, interesting teaching content, willingness to communicate with the instructor and satisfaction (Table 3).

Discussion

Our study showed that physicians in the 3D-printed hip model combined with CBL group outperformed those in the traditional teaching group in both theoretical and clinical practice skills assessment, which mainly included

Table 3 Comparison of questionnaire results between the two groups

Item	CBL group	3D+CBL group	T value	P value
Hip joint fundamentals	6.57 ± 1.11	7.28 ± 1.53	2.936	0.004
Ability to diagnose cases and plan treatment	5.27 ± 1.19	6.98 ± 1.48	7.003	<0.001
Interesting teaching content	6.03 ± 1.38	7.825 ± 1.25	7.575	<0.001
Willingness to communicate with lead teachers	5.92 ± 1.01	7.38 ± 1.52	6.221	<0.001
Teaching satisfaction	6.92 ± 1.51	8.05 ± 1.40	4.270	<0.001

understanding and mastery of imaging features, diagnosis and treatment of osteoarthritic disorders, and surgical protocols. Chen et al [18] conducted a study investigating the use of 3D printing in combination with PBL in the teaching of surgical skills for the Henle torso variant. The experimental group received traditional classroom instruction supplemented with 3D-printed models, while the control group received a 2D image of the henle trunk plus surgical video. The results showed that the experimental group performed significantly better than the control group in both theoretical knowledge and practical skills. A systematic review by Asif [19] revealed that patient-specific 3D-printed (3DP) models have been used for clinical training in the UK, especially for rarer and more complex conditions, and that 3DP models are associated with greater user satisfaction and good short-term teaching outcomes. Another study by Sun et al [20] investigated the application of 3D visualisation combined with project-based learning (PBL) in teaching about spinal disease. The study involved 106 medical students who were randomised into two groups: a group incorporating PBL instruction and a traditional lecture-based classroom group. The researchers concluded that the combination of 3D visualisation and PBL was effective in improving learning outcomes in spine surgery. Studies have shown that the use of 3D-printed models of patient joints can help surgeons better plan and perform surgery [21, 22].

Our findings are consistent with previous studies emphasising the pedagogical benefits of incorporating 3D-printed models into surgical training [18, 23, 24]. The tactile and visual advantages provided by these models allow students to have physical access to anatomical structures, greatly improving their understanding of complex joint surgeries [25, 26]. As our study demonstrates, this hands-on learning approach leads to better mastery of theoretical knowledge and practical skills. CBL is a teaching methodology that uses cases as a basis and puts empty theories into the context of specific cases for exposition. The use of 3D printing in CBL enables students to solve real-world problems [27]. In addition, the integration of 3D-printed hip models with CBL promotes

active learning and critical thinking while enhancing students' mastery of orthopedic theoretical knowledge and basic orthopedic operative skills, expanding their clinical thinking, promoting interest and motivation in orthopedic clerkships, and improving their satisfaction with traditional teaching. The interactive nature of CBL encourages students to deal with real-world surgical scenarios and develop problem-solving abilities that are critical problem-solving skills [28]. This combination of teaching methods not only improves student understanding but also contributes to improved surgical outcomes, consistent with the broader goals of medical education. The findings presented in this paper are consistent with those of previous studies exploring the integration of 3D printing and CBL in medical education. Similar positive results have been reported in studies of related areas such as spinal surgery and rare clinical conditions [20]. All of these results suggest that if the technology is extended to medical schools, it could improve teaching and learning outcomes and enhance quality to some extent.

A CBL teaching method that incorporates 3D-printed models can have implications for traditional teaching and learning. This interactive learning method can be used as a complementary tool to enhance traditional classroom instruction, especially in understanding complex medical and surgical concepts [5, 8, 29]. Students' engagement and interest can be increased through the combination of visual and tactile use of 3D-printed models and dynamic learning experience in the CBL teaching method. At the same time, instructors can introduce active learning and critical thinking into the traditional classroom, guiding students to analyse problems and explore solutions in a more holistic manner and improving overall teaching and learning outcomes [26]. There are many advantages to using triple 3D-printed models as an alternative to actual anatomical specimens in medical education. First, 3D models provide more vivid and clearer visualisations, helping students understand human structures in a more intuitive way [25]. Second, compared to actual anatomical specimens, 3D models are not limited by time and place, simplifying the teaching process. Educators can also customise different scenarios and content to meet the learning needs and teaching goals of different students, which is especially applicable in personalised case teaching, helping to discuss personalised treatment plans. In contrast, the use of real anatomical specimens involves ethical issues and difficulties, especially for rare lesion specimens from patients with DDH [30]. Moreover, anatomical specimens may deteriorate, rot or deform over time, making maintenance difficult. In summary, the use of 3D-printed models helps to compensate for the scarcity of anatomical specimens, avoids ethical issues, improves teaching efficiency, and promotes research innovation. This alternative method provides

new possibilities and opportunities for medical education and research.

Limitations of the study include the following: ① The sample size and scope limitations include the fact that the study included only 120 students, which may limit the generalizability of the results. In addition, all participants were from the same educational institution, which may have biased their geographical and educational backgrounds. ② Study design: Although randomised grouping was used, it was not clear whether there was a blinded design, i.e., whether the raters and the participants were aware of the group to which they were assigned, which may have affected the objectivity of the results. ③ Validation of the assessment tool: The study used a self-administered questionnaire to conduct the assessment, and the degree of standardisation and validation was not specified. The degree of standardisation and validation was not described in detail, which may have affected the accuracy and reliability of the results. ④ Unknown long-term effects: This study focused mainly on teaching and learning effects in the short term and failed to assess long-term learning outcomes and skill retention. Future research needs to delve deeper into the use of different types of 3D-printed models in orthopedic education and expand beyond the current focus on DDH to other orthopedic areas, such as knee disorders and spinal disorders, to explore the effectiveness of CBL teaching methods that incorporate 3D printing. Future research will also require long-term follow-up studies to assess the lasting impact of the teaching approach on students' clinical skills and knowledge retention. These studies will provide new insights and innovations to the field of orthopaedic education.

Conclusions

The combination of 3D printing and case-based learning has yielded positive results in treating DDH, providing valuable insights into the use of 3D-printed orthopedic molds in clinical teaching.

Abbreviations

CBL	Case-Based Learning
PBL	Project-Based Learning
3D	Three-Dimensional
DDH	developmental dysplasia of the Hip

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12909-024-05934-w>.

Supplementary Material 1

Author contributions

F.S. and S.Y.J. wrote the main manuscript text and analysed the data. Z.Q.R. and S.S.F. prepared the figures and tables. Z.Y.S. was responsible for collecting

and collating data. Y.F. was responsible for the research design and article evaluation.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Affiliated Hospital of Xuzhou Medical University (XYFY2023-KL146-01) and was exempted from review.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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