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The utilization of 3D pelvis model to improve the ability to understand complex anatomy among orthopaedic surgical trainees

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Abstract

Background There is growing data and revolution for three-dimensional (3D) model use for multiple purposes included clinical and health professional education. While the 3D model of human body is utilized frequently during surgical procedures with beneficial effects, however, its usefulness for the surgical trainees at their education yet not evaluated.

Objective To evaluate is the 3D pelvis model helpful for the trainees to improve their ability and to understand complex pelvis anatomy. And the question, Does the hands-on use of a 3D model of a normal pelvis improve the trainee's knowledge of the technical skills to understand complex pelvic anatomy?

Methods The existing literature had been reviewed using PRISMA guideline and formulated this quantitative design study. The participants have been recruited through local orthopedic residency program. 29 trainees divided into two groups, experimental group with 3D pelvis model and control group without the model, based on their year of training experiences and gender. Both groups have been asked to solve a knowledge test that is created through Delphi process method. As well, all participants requested to read pre-test educational materials.

Results There were 14 residents at each group (one participant were excluded). The experimental group had higher overall scores than the control group, and specifically better at the anatomy questions subgroup (P value = 0.019, P value = 0.006 respectively). There was not statistically significance difference for the time required to complete the test between the two groups. At our study, we found the females scored higher than males.

Conclusion 3D model showed the beneficial role among orthopedics trainees to enhance their ability for understanding complex pelvis anatomy. We recommended further studies with well-designed and larger numbers among different surgical subspecialties and/or among different orthopedics sites.

Keywords Acetabular fracture, 3D printed model, Pelvic, Orthopaedic trainees, Medical education

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Introduction

Three-dimensional (3D) printing is an innovative, rapidly growing technology that is gaining popularity in various medical fields [1–2]. It has found wide-ranging applications, including preoperative planning, intraoperative guidance, surgical simulation navigation, and the creation of custom-tailored implants and prostheses [3, 4, 5]. Beyond their clinical applications, 3D printed models serve as valuable educational aids, enhancing learning experiences for medical trainees [6, 7, 8]. Preliminary studies have suggested that these models enhance knowledge of complex anatomy and understanding of difficult concepts for medical trainees [9]. However, a less publicized application of 3D printed models is their use as educational tools [10].

Surgical procedures involving intricate anatomical structures can be particularly challenging for surgical trainees to master [11–12]. In orthopedic surgery, the pelvis, with its complex bone anatomy, is one such structure that requires special attention [13]. A thorough understanding of the anatomy is essential, as the management using different surgical approaches and techniques varies according to the pathology (Image 1). 3D printed models can be valuable tools for learning the complex anatomy of the pelvic bone, especially in cases of acetabular fractures [14–15].

A comprehensive literature review was conducted to examine the existing evidence on the educational benefits of 3D models for surgical trainees. While the positive impact of 3D models on preoperative planning and intraoperative guidance for surgeons is well-established, their effectiveness in enhancing trainee understanding of complex anatomy remains less clear [16]. The available literature lacks conclusive evidence regarding the objective benefits of using 3D models for educational purposes [17–18]. Therefore, the aim of this study is to investigate whether providing pelvic 3D modules can improve learning outcomes in orthopedic trainees. Specifically, the study will evaluate if these models can enhance understanding of complex anatomy, surgical approaches and techniques, and radiological evaluation of the acetabulum. Additionally, if the study finds that 3D models are beneficial, it will explore methods to quantify these positive effects [19–20].

Image 1 A 3D printed pelvic module with a tumor

Materials and methods

Participant recruitment

The participants were recruited through a local orthopedic residency program (Oman Medical Specialty Board, OMSB). We targeted the maximum number of all residents in Orthopaedics after invitation through emails. Only orthopedic residents were included due to the complex nature of pelvic anatomy and the unique focus on acetabular fractures. Thus, we eliminated the general surgery, obstetrics, and gynecology programs from this study. The recruitment process and data collection were conducted by a different individual than the data analyst to ensure objectivity and prevent any potential biases from influencing the results. Thus, the analyst had the participants' scores with a coded population and was blinded to whom these scores belonged.

Group formation and randomization

A total of 29 residents volunteered to participate. Participants were divided into two groups: an experimental group with access to a 3D pelvic model and a control group. Groups were randomized based on the year of training and gender to minimize bias and ensure a balanced distribution of participants across the groups. To ensure balanced representation, separate lists were created for male and female participants. Participants were arranged in descending order based on their OMSB trainee number. Participants were then alternately assigned to the experimental and control groups. For example, in male PGY-5, the participant with the highest trainee number was assigned to the experimental group, followed by the participant with the next highest trainee number being assigned to the control group. This process ensured balanced representation of participants based on both trainee number and gender.

Pre-Test and teaching materials To improve the internal validity of the study and due to the stratified randomization process, a pre-test was not administered. However, all participants were provided with standardized teaching material on acetabulum fractures prior to the test. The teaching material was sent to all participants just prior to their presentation for the test, and they were instructed to read the material. The materials covered all essential topics related to acetabulum fracture management. Upon reviewing the material, it included most of the information residents would need to answer the test, but the questions required a level of 3D visualization to solve them effectively.

Image 2 A 3D model of a normal pelvic bone

A standard 3D pelvic model was used. To validate it for educational use, the model was checked against anatomical textbooks and peer-reviewed literature to ensure accuracy [21–22]. Orthopedic surgeons and educators assessed its realism and educational value. Additionally, medical students and residents utilized the model in training sessions, providing feedback on its effectiveness in teaching pelvic anatomy and fracture management.

Test development and validation

To measure the trainees' skills knowledge, we opted for a knowledge test over a questionnaire. The test aimed to quantify the effectiveness of 3D models in surgical training and assess the trainees' 3D visualization skills. The test focused on unique and complex knowledge related to pelvic pathology, particularly surgical skills. Due to the lack of existing validated tools, the questions were created and edited by the senior author, an expert in acetabulum fractures. Three blinded reviewers further refined the questions using the Delphi process. A qualified exam question writer reviewed the questions' style and formatting. The test was specifically designed for this study to address the research objectives.

To ensure comprehensive assessment, the test covered a wide range of concepts related to acetabulum fractures. The test consisted of 20 questions that focused on surgical skills and anatomy. The questions were divided into four subgroups: anatomy, surgical approaches, radiographic landmarks, and technical questions. Each subgroup contained 5 questions. This structure ensured valid assessment of the trainees' knowledge in all relevant areas.

Data collection and analysis

The experimental group (with 3D pelvic models on hand for each participant) and the control group (without 3D models) were assigned to separate rooms to complete the test. The 3D pelvic model used is shown in the image (Image 2). The knowledge test was conducted in the OMSB simulation center during the weekly academic sessions. Reminder emails were sent to trainees the week before the test. Upon completion, test scores were collected and organized in an Excel sheet by the co-investigator. Participant data was coded and submitted to the data analyst in a blinded format. The Excel data was converted to SPSS (IMB SPSS Statistics Version 29.0.2.0 (20)) for analysis. Inferential statistics, such as t-tests, were used to compare the mean scores between the two groups. A 95% confidence interval and a p-value of 0.05 were used to determine significant correlations.

The following flowchart illustrates the process of materials creation, participant recruitment, and grouping used in the study (Fig. 1).

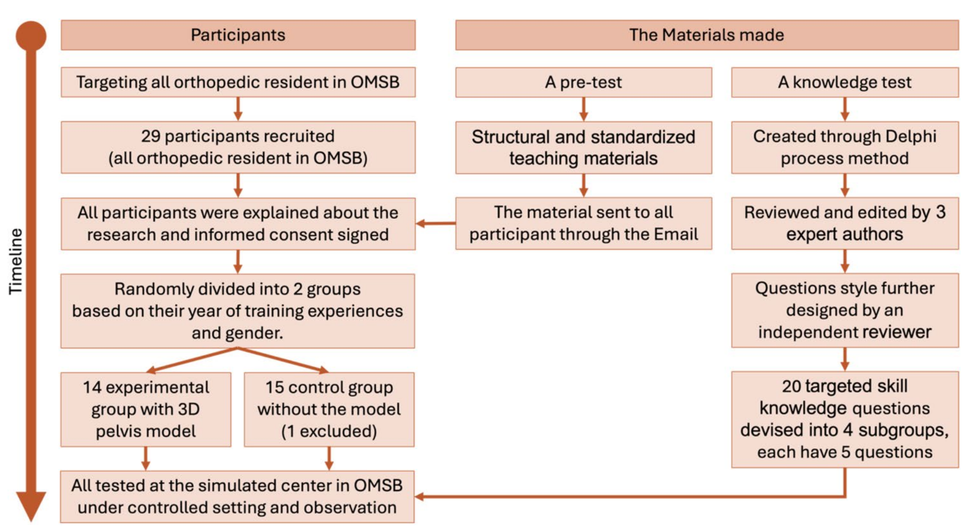

Fig. 1 Study methodology flow chart. OMSB: Oman Medical Speciality Board

Table 1 The recruited participants to the study based on their level of training and gender. PGY: post graduate year. M: male. F: female

Year of Training	Experimental Group (M/F)	Control Group (M/F)	Total (M/F)
PGY-1	3 (3/0)	3 (2/1)	**6 (5/1)**
PGY-2	2 (1/1)	3 (2/1)	**5 (3/2)**
PGY-3	3 (1/2)	2 (1/1)	**5 (2/3)**
PGY-4	2 (2/0)	3 (2/1)	**5 (4/1)**
PGY-5	4 (3/1)	3 (3/0)	**7 (6/1)**
Total	**14 (10/4)**	**14 (10/4)**	**28 (20/8)**

Results

Participant recruitment and demographics

All eligible residents (29) voluntarily participated in the study. The study included 15 participants in the control group and 14 participants in the experimental group. One participant was excluded from the control group due to duplicate responses and exceeding the time limit, which is 30 min. This resulted in 14 participants in each group (Table 1). The orthopedic program had a higher number of male residents compared to female residents (Fig. 2).

Procedure experience assessment

Despite providing pre-test educational materials, we wanted to assess the participants' core training and experience with pelvic procedures. We asked them to indicate their previous exposure to pelvic surgeries. Participants were given three options: no exposure, 1–5 procedures, or more than 5 procedures. Most participants (57%, 16 trainees) had 1–5 previous procedures. Seven participants had more than 5 procedures, and five participants had no exposure. Senior residents were more likely to have higher procedure exposure ($p < 0.001$, and 95% Confidence Intervals = 0.325–0.808). However, the distribution of procedure experience was relatively balanced between the groups, with similar numbers of participants in each group having high, medium, and low exposure (P value was 1, strongly non-significant, and Pearson Correlation was 0.00). This helped to ensure equal representation across all experience levels (Fig. 3).

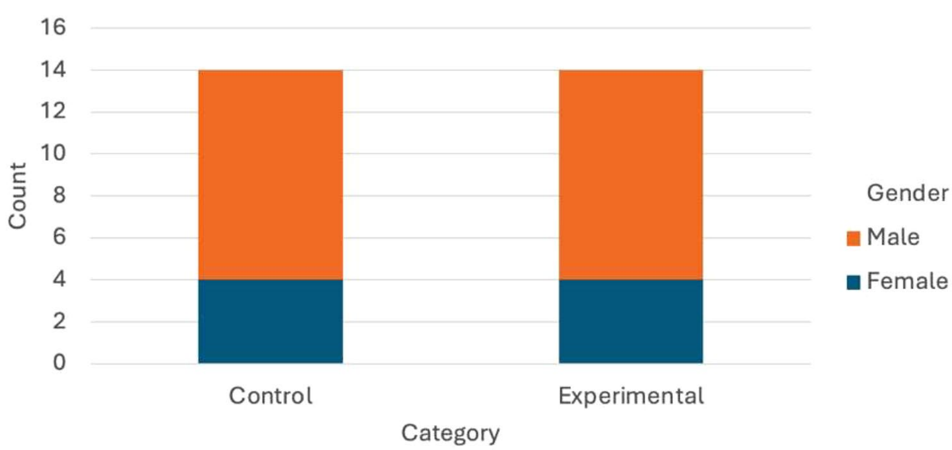

Fig. 2 The Bar chart for gender distribution at Orthopedics residency program

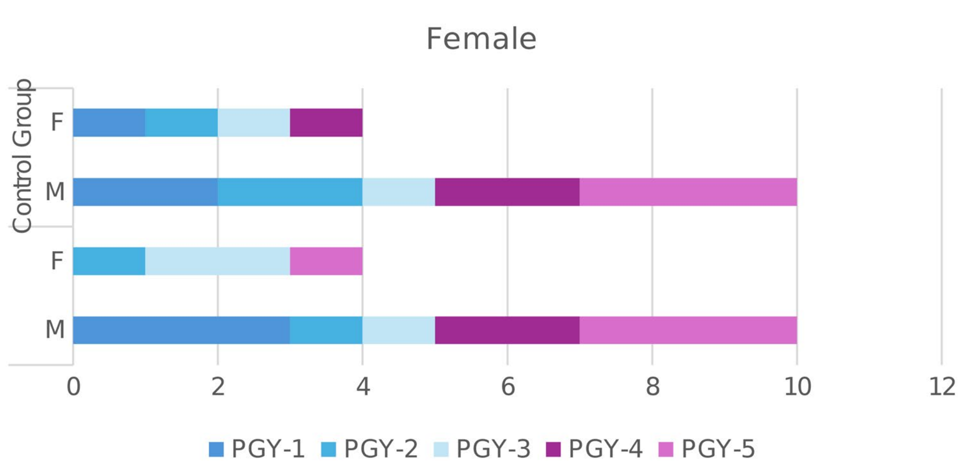

Fig. 3 The Bar chart for the residency level of od the trainee and gender distribution in both groups. PGY: post graduate year. M: male. F: Female

Table 2 The means for total score and subcategory for all trainees. N: number. Std. deviation: standard deviation

Descriptive Statistics					
	N	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Total Anatomy	28	0	5	3.32	1.219
Total Radiology	28	1	5	4.14	1.008
Total Approach	28	0	5	2.50	1.202
Total technique	28	0	5	1.93	1.331
Total Score	28	5	20	11.86	2.965
Time in Minutes	28	5	26	15.86	5.169

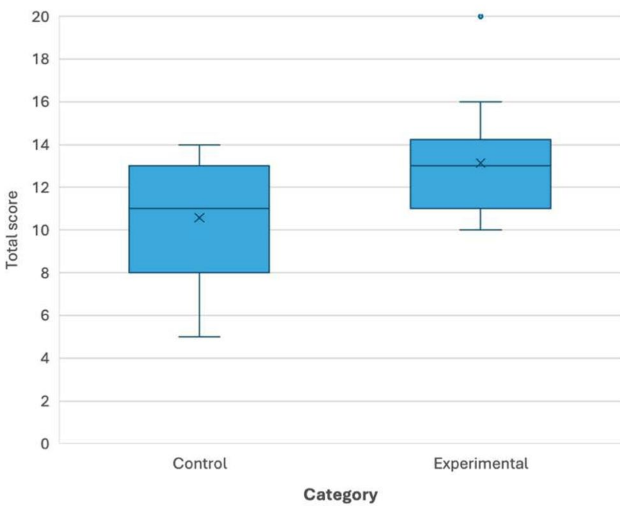

Fig. 4 The relationship Boxplot in the association between study groups and total scores. It showed the higher scores lined up with the experimental group

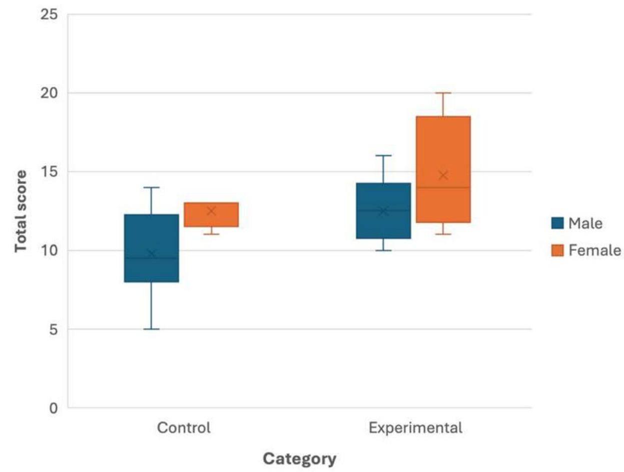

Fig. 5 The relationship Boxplot in the association between the gender and total scores. It showed the females had higher scores at both groups

Test performance

The average total score for all participants was 11.9 out of 20 (Table 2). Participants completed the test in an average of 15 min with a standard deviation of 5 min. Participants performed well on radiology questions, with an average score of 4.1 out of 5. However, they struggled with technique questions, scoring an average of 1.9 out of 5 (Table 2).

Key findings

There was a significant association between study group and total score. The experimental group significantly outperformed the control group ($p = 0.019$, and 95% Confidence Intervals = 0.082–0.699). The boxplot in Fig. (4) visually demonstrates this relationship, showing higher scores in the experimental group. A moderately positive correlation was found between study group and total score (Pearson Correlation = 0.44).

Additional findings

The experimental group significantly outperformed the control group in anatomy questions ($p = 0.006$, and 95% Confidence Intervals = 0.166–0.740). There were no significant differences between the groups in radiology, approach, or technique questions. Contrary to expectations, the experimental group did not complete the test significantly faster than the control group. Both groups finished within the allotted time with not statistically significance (P value = 0.618, and 95% Confidence Intervals = -0.285–0.455).

To examine potential biases, we analyzed the relationship between gender, year of training, and procedure experience on test scores. Females significantly outperformed males ($p = 0.044$, and 95% Confidence Intervals = 0.013–0.662). Figure (5) visually represents this gender-based difference in scores. Despite this finding, the study groups were well-balanced in terms of gender distribution.

Contrary to expectations, there was no significant difference in performance between senior residents and junior residents. While senior residents had more procedure experience (P value = < 0.001, and 95% Confidence Intervals = 0.325–0.808), their test scores were similar to those of junior residents (P value = 0.113, and 95% Confidence Intervals = -0.092–0.599). This suggests that the 3D model in the experimental group was a key factor in performance, rather than years of training. There was also no significant correlation between total scores and the number of previous pelvis procedures (P value = 0.236, and 95% Confidence Intervals = -0.155–0.557), indicating that the results were not influenced by participants' prior experience).

Discussion

The study aimed to investigate the impact of 3D pelvic models on trainee understanding of complex pelvis anatomy and technical skills. The research question focused on whether the hands-on use of a 3D normal pelvic model could improve trainee's knowledge of technical skills.

To minimize selection bias, the groups were equally balanced in terms of the number of residents, year of training, seniority level, gender, and previous procedure experience. The equal distribution of these variables ensured that the groups were comparable and reduced the influence of confounding factors. Previous procedure experience could have been a confounding variable. However, the study successfully achieved equalization in this regard, ensuring that the groups were similar in terms of exposure to pelvic procedures. This mitigated the potential impact of confounding variables [10, 19].

The experimental group demonstrated higher overall scores compared to the control group. Participants in the experimental group excelled in anatomy questions, particularly when compared to radiology, approach, and technique questions. This suggests that the 3D pelvic model may be beneficial for understanding complex anatomy and improving performance on skill-based tests. The findings demonstrated that 3D printed models can enhance understanding of anatomical structures and spatial relationships [6–7].

Similar findings have been reported regarding the benefit of 3D models in education for medical students. Meyer et al. investigated the impact of 3D stereoscopic models on first-year medical students' short- and long-term retention. They found that students showed significantly higher retention immediately after using the 3D model, but this effect diminished over time [23]. Zhang et al. evaluated the use of 3D printed pelvic fracture models for preoperative planning. They demonstrated that 3D models improved understanding of anatomical structures and reduced complications during surgery. This aligns with our findings that 3D models enhance understanding of complex anatomy and technical skills, demonstrating their broad applicability in medical education and practice [13]. Kiesel et al. evaluated the value of a 3D printed model for training of gynecological pelvic examination. They found that the 3D printed model improved practical teaching of the gynecological pelvic examination for medical students. Similar to our study, this research highlights the benefits of 3D models in enhancing practical skills and understanding of anatomy [14].

Senior residents were expected to outperform junior residents due to their greater experience. However, there was no significant difference in performance based on year of training or previous procedure exposure. This suggests that the 3D model in the experimental group was the primary factor contributing to higher scores, rather than experience. The elimination of confounding variables strengthens the conclusion that the 3D model was the key contributor to the improved performance. In contrast, Montgomery et al. found that while 3D models improved confidence, the effect was less pronounced in more senior residents, suggesting that experience still plays a role [15]. The difference in findings could be due to the specific focus of each study: our study focused on pelvic anatomy and technical skills, while Montgomery et al. focused on calcaneal fractures and fracture understanding [12, 16].

Unexpectedly, two additional factors emerged from the study: time to complete the test and gender difference. Despite expectations, the experimental group did not complete the test significantly faster than the control group. One possible explanation is that participants in the experimental group may have taken more time to ensure accurate answers due to the hands-on use of the 3D model. This finding is novel and has not been previously reported in the literature. Despite equalizing gender distribution between the groups, this gender difference persisted. This finding could be attributed to underpowering of the study or a specific trend among orthopedic surgical residents. While orthopedics has historically been male-dominated, recent trends show increasing female representation. Studies have supported the comparable performance of female orthopedic residents [24, 25].

Study limitations

The limited number of participants was a significant limitation due to the focus on a single orthopedic training program. The study was limited to orthopedic residents, which may limit the applicability of the results to other surgical specialties. While a 100% response rate was achieved, power analysis was not conducted due to the small sample size. The knowledge test was not a validated instrument, although it was developed and reviewed by experts. Pre-test material engagement was not directly assessed.

The knowledge test was not a validated instrument, although it was developed and reviewed by experts (using the Delphi method). It is uncertain if all participants fully engaged with the pre-test material, as it wasn't directly assessed. The generalizability of the findings is limited to the single site and orthopedic training program.

Future research directions

The study focused on pre-operative knowledge assessment. As we approved the beneficial of 3D model in theoretical exam (specifically in anatomy), further research is needed to evaluate the effectiveness of 3D models during actual surgery.

Larger-scale studies with multiple sites and diverse surgical subspecialties are needed to improve generalizability. Investigating the effectiveness of 3D models in the operating room for intraoperative guidance is a promising area for future research. Developing validated knowledge tests and assessing pre-test material engagement can enhance the study's rigor. Exploring the potential benefits of 3D models for non-complex pathologies and non-orthopedic procedures is another avenue for future research.

Overall, while the study provides valuable insights, addressing these limitations through future research can strengthen the evidence base and broaden the applicability of the findings.

Conclusion and recommendations

The experimental design demonstrated the beneficial impact of 3D models on orthopedic trainees' test performance and understanding of complex pelvis anatomy. Trainees in the experimental group excelled in anatomy questions compared to other test categories. There was no significant difference in time to complete the test between the groups. Females outperformed males, but this finding may be influenced by factors such as small sample size.

Larger-scale randomized trials with diverse surgical pathologies are recommended. Translating the use of 3D models into surgical educational practice is essential. Future research should focus on the impact of 3D models during actual surgery, including measuring their usage by trainees and surgeons. Investigating the effectiveness of 3D models for different pathologies and surgical specialties is another area for exploration. Overall, the study provides strong evidence for the benefits of 3D models in orthopedic training. Future research can further expand our understanding and guide the implementation of 3D models in surgical education.

Abbreviations

3D	Three-Dimensional
F	Female
M	Male
OMSB	Oman Medical Specialty Board

Supplementary Information

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Supplementary Material 1

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Author contributions

Ahmed And Humaid are the main authors wrote the manuscript and the did the experimental studyMoosa helps in preparing the site for the test conductionMohamed, Ahmed, Mohammed al mutant helped in creating the test.

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Data availability

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

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Ethical approval for this study was obtained from the Sultan Qaboos University Medical Research Ethics Committee and the Research and Innovation Committee of the Oman Medical Specialty Board. Informed consent was obtained from all participants prior to their involvement in the study.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

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