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Performance and perception of dental students using a haptic simulator for tooth preparation of a metal-free crown

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ABSTRACT

Objective: To describe performance and analyze the perception of dental students from a private university in Metropolitan Lima when using a haptic simulator for tooth preparation of a metal-free crown in the posterior region. **Materials and methods:** A cross-sectional, descriptive, and observational study was conducted. A total of 27 students participated, performing tooth preparation for a metal-free crown on a mandibular molar using the Simodont® Dental Trainer haptic simulator. Performance was assessed using a six-parameter rubric (maximum score: 20 points), and the activity was classified as pass (≥11) or fail (<11). Perception of the simulator's usefulness was measured using a five-point Likert-type survey. Descriptive and bivariate analyses were conducted using nonparametric tests ($p < 0.05$). **Results:** 66.67% of students failed the global manual dexterity assessment. Occlusal reduction showed the highest proportion of unacceptable results (70.37%), and 100% of participants affected adjacent teeth. In contrast, the convergence angle showed 74.07% satisfactory results. Overall perception of the simulator was positive (median = 4). Significant associations were found between performance in occlusal reduction and perceived similarity to a real dental handpiece ($p = 0.041$) and handpiece control ($p = 0.043$), as well as between convergence angle and manual comfort ($p = 0.010$). **Conclusions:** Although students showed a favorable perception of the haptic simulator, technical performance was predominantly suboptimal. These findings suggest that positive perception does not necessarily translate into immediate clinical competence. Haptic simulation should be integrated in a structured and progressive manner within preclinical training, consistently incorporating instructor feedback.

Keywords: simulation training; haptic technology; motor skills; dental education; virtual reality.

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INTRODUCTION

Dental education integrates theoretical and practical components, both of which are essential for developing the clinical skills required for professional practice. The traditional clinical learning model involves the patient, the student, and the instructor, who plays a fundamental role in supervising and providing feedback throughout the training process. However, this model presents important limitations, such as the availability and variability of clinical cases, as well as ethical considerations inherent to patient care, which restrict the deliberate repetition of procedures (1,2).

Given the limitations of the real clinical environment, the preclinical phase is crucial in dental education as it allows the consolidation of manual dexterity in a controlled environment before interacting with patients. The use of phantom heads has been a widely adopted strategy for this purpose. However, this type of simulation requires constant supervision, presents limitations in replicating certain procedures, and entails additional costs when multiple repetitions are required (3). These factors have driven the incorporation of new educational technologies aimed at optimizing clinical training (4).

In this context, haptic simulators have emerged as an innovative tool capable of replicating clinical procedures in virtual environments without posing any risk to the patient. These devices provide real-time sensory feedback, enable unlimited repetition of exercises (5–7), and offer objective metrics for performance evaluation, which promotes self-assessment and greater student autonomy (8). Several studies report that their use contributes to the development of fine psychomotor skills and strengthens manual dexterity during the preclinical stage (5–8).

Among the available simulators, Simodont® Dental Trainer (Nissin, Japan), developed in 2009 in Amsterdam, the Netherlands, has been incorporated into various academic programs as a complementary tool (5). Although evidence supports its general utility, findings reported in the literature are heterogeneous and depend on the type of procedure, educational context, and measurement criteria employed (9,10). In particular, specific evidence regarding its use in oral rehabilitation procedures remains limited.

Nowadays, metal-free crowns, such as lithium disilicate and zirconia crowns, constitute the treatment of choice in oral rehabilitation due to their mechanical, esthetic, and biocompatibility advantages over metal-ceramic restorations (11). Tooth preparation for these restorations requires a high degree of technical precision, including control of occlusal and axial reduction, establishment of an optimal convergence angle, definition of the cervical finish line, and preservation of adjacent teeth. These requirements make metal-free crown tooth preparation a clinically relevant model for the objective assessment of manual dexterity.

Despite the increasing adoption of this technology, evidence regarding its impact on student performance during tooth preparation of metal-free crowns remains limited, particularly in Latin American contexts. Similarly, few studies simultaneously integrate objective assessment using standardized parameters and the subjective perceptions of students. This lack of information hinders the establishment of clear pedagogical recommendations in the field of oral rehabilitation.

For these reasons, the objective of this study was to describe performance and analyze the perceptions of stomatology students at a private university in Metropolitan Lima while using a haptic simulator for tooth preparation of a posterior metal-free crown.

MATERIALS AND METHODS

A cross-sectional and descriptive study was conducted at the Faculty of Stomatology of a private university in Metropolitan Lima. The population comprised all students enrolled in the Adult Clinical Stomatology Internship course (n = 27). Inclusion criteria were voluntary participation and current enrollment status. Participants could have prior experience or no experience with haptic simulators in procedures other than crown tooth preparation. Students with previous experience using these simulators for the tooth preparation of posterior metal-free crowns, as well as those presenting visual, auditory, or psychomotor limitations, were excluded. The study received approval from the Institutional Ethics Committee of Universidad Peruana Cayetano Heredia (SIDISI code 213188, certificate CIE-313-27-24), and informed consent was obtained from all participants.

Two instruments were used for the evaluation. The first was a rubric designed to assess manual dexterity in tooth preparation, consisting of six parameters and a maximum score of 20 points, which allowed classification of the activity as pass (≥11) or fail (<11) (Table 1). The second instrument was a perception survey regarding the usefulness of haptic simulators, consisting of eight questions answered on a five-point Likert scale (1 = "less useful"; 5 = "very useful").

Both instruments were adapted from previous studies (12,13) and underwent a content validation process through expert judgment. Six faculty members in the areas of occlusion and oral rehabilitation participated, each with at least 5 years of teaching experience. The reliability of the survey was assessed using Cronbach's alpha coefficient, obtaining a value of 0.6.

Table 1. Evaluation rubric for manual dexterity in tooth preparation for a posterior metal-free crown using the Simodont® Dental Trainer haptic simulator.

Parameter	Indicator	Unacceptable	Acceptable	Satisfactory
Occlusal reduction	Reduction in millimeters of the occlusal surface in a buccolingual or palatal view	Occlusal reduction <2 mm or >2.5 mm (0 points)	Occlusal reduction >2.0 mm and ≤2.5 mm (2 points)	Occlusal reduction of 2.0 mm (3 points)
Axial reduction	Reduction in millimeters of all tooth surfaces	Axial reduction <1.5 mm or >2.0 mm (0 points)	Axial reduction >1.5 mm and ≤2 mm (2 points)	Axial reduction of 1.5 mm (5 points)
Occlusal convergence angle	Angle formed between the two opposing walls of a preparation that gradually converges occlusally	Angle <6° or >20° (0 points)	Angle ≤20° and >10° (2 points)	Angle ≥6° and ≤10° (3 points)
Location of the cervical finish line	Location of the finish line using the gingival margin as reference	Cervical finish line more than 1 mm supragingival or more than 0.5 mm subgingival (0 points)	Cervical finish line no more than 1 mm supragingival and no less than 0.5 mm subgingival (2 points)	Cervical finish line extending from the gingival margin to 0.5 mm supragingival (3 points)
Type of cervical finish line	Shape of the finish line, evaluated from the midpoint of the four tooth surfaces	No finish line observed (0 points)	Chamfer-type finish line partially observed (2 points)	Well-defined chamfer finish line observed on the four free surfaces (3 points)
Preservation of adjacent teeth	Number of adjacent teeth affected during preparation	Adjacent teeth affected (0 points)		No adjacent teeth affected (3 points)

Before the study began, a calibration process was conducted among three raters through the joint review of cases under the supervision of an expert faculty member. The raters were dental school graduates who, during their training, had received instruction in metal-free crowns and the use of haptic simulators. Subsequently, a pilot study was conducted with nine first-year oral rehabilitation specialty students to assess the applicability and consistency of the instruments.

Students were invited to the haptic virtual reality center and assigned a simulator unit under an anonymous user profile. Before the practical activity, they attended a 10-minute theoretical session conducted by a specialist faculty member, during which the clinical parameters for tooth preparation and the evaluation rubric criteria were explained. Students then performed tooth preparation on a mandibular molar. The simulator allowed visualization from different angles and the use of the zoom tool. Students were given a maximum time of one hour and were allowed unlimited attempts; however, for analysis purposes, only the best tooth preparation, according to each student's judgment, was considered. Upon completion, participants completed an anonymous virtual survey regarding their perception of the simulator's usefulness.

The evaluation of the preparations was performed by the raters using the rubric and the virtual tools of the Simodont® Dental Trainer system, such as the virtual millimeter ruler, the angle gauge, and the superimposition of the tooth before tooth preparation (Figure 1). These tools enabled objective and precise measurements.

Data were processed in Microsoft Excel and exported to the statistical software Stata v. 18.0 for analysis, considering a 95% confidence level ($p < 0.05$). For qualitative variables, absolute and relative frequencies were calculated; for quantitative variables, the median and the 25th and 75th percentiles were determined. Data normality was assessed using the Shapiro–Wilk test. The bivariate analysis explored the association between the perceived usefulness of the simulators and the manual dexterity parameters assessed during the preparation of metal-free crowns. The association between overall performance (pass/fail) and perceived usefulness was also determined using the Kruskal–Wallis and Mann–Whitney U tests, respectively, considering a statistical significance level of $p < 0.05$.

RESULTS

Table 2 details students' performance in the tooth preparation of a posterior metal-free crown using haptic simulation, evaluated through six specific clinical parameters. Overall, 66.67% of the students (n = 18) were classified as fail, whereas 33.33% (n = 9) achieved a passing level according to the total score obtained from the applied rubric.

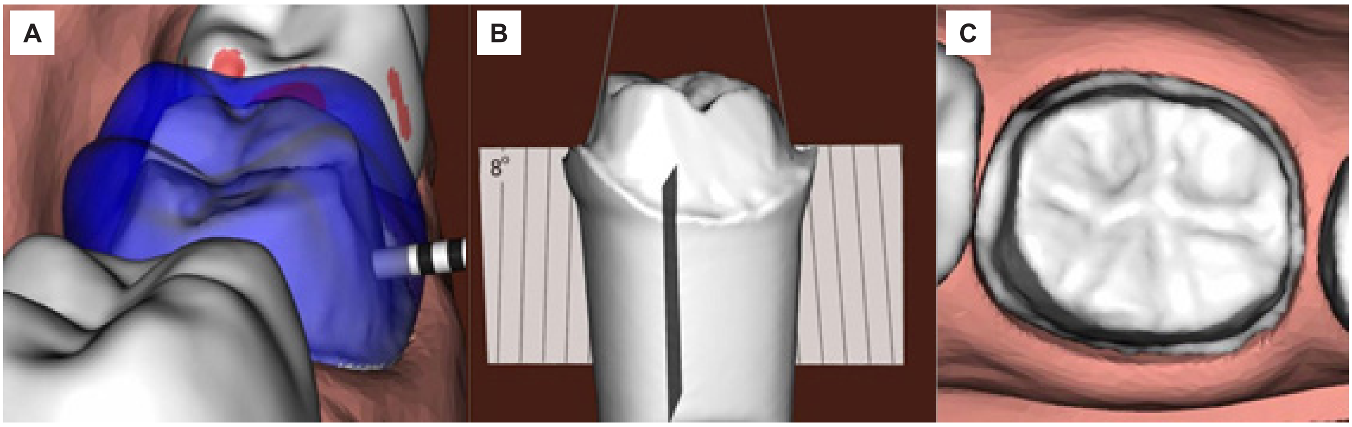

Figure 1. Evaluation of tooth preparation of a metal-free crown using a haptic simulator. A) Measurement of the amount of reduction. B) Measurement of the occlusal convergence angle. C) Occlusal view.

Table 2. Distribution of manual dexterity performance in tooth preparation of a posterior metal-free crown using a haptic simulator.

Manual dexterity	Unacceptable		Acceptable		Satisfactory	
	n	%	n	%	n	%
Occlusal reduction	19	70.37	4	14.82	4	14.81
Axial reduction	3	11.11	18	66.67	6	22.22
Occlusal convergence angle	4	14.81	3	11.11	20	74.07
Location of the cervical finish line	7	25.93	16	59.26	4	14.81
Type of cervical finish line	7	25.93	15	55.56	5	18.52
Preservation of adjacent teeth	27	100.00	0	0	0	0.00
	Pass		**Fail**			
	9	33.33	18	66.67		
Total	27	100.00				

The parameter-based analysis revealed variable performance. Occlusal reduction showed a high proportion of unacceptable results (70.37%; n = 19), with equivalent percentages of acceptable (14.82%; n = 4) and satisfactory (14.81%; n = 4) evaluations. In contrast, axial reduction predominantly yielded acceptable results (66.67%; n = 18), followed by satisfactory evaluations (22.22%; n = 6) and a smaller proportion of unacceptable results (11.11%; n = 3).

The occlusal convergence angle was the best-performing parameter: 74.07% of the preparations (n = 20) were rated as satisfactory, whereas unacceptable and acceptable results accounted for 14.81% (n = 4) and 11.11% (n = 3), respectively.

Regarding the cervical finish line, both its location and type were predominantly rated as acceptable (59.26% and 55.56%, respectively), with lower proportions of satisfactory (14.81% and 18.52%) and unacceptable results (25.93% in both cases). Preservation of adjacent teeth demonstrated the poorest performance, as 100% of the preparations (n = 27) were classified as unacceptable.

Table 3 summarizes students' perceptions regarding the usefulness of haptic simulators in learning and clinical training. In general, a favorable evaluation was observed, with median values of 4 across seven of the eight items, indicating a positive and relatively homogeneous perception of this technology as an educational tool. Students highlighted the usefulness of the simulator for self-directed learning and training in posterior crown preparation. At the same time, they emphasized the similarity of the haptic sensation and the control of the simulator handpiece compared with a high-speed handpiece used on a real tooth (median = 4 in both cases). The realism of the anatomical models and the usefulness of the system as a tool for evaluating manual dexterity were also positively rated.

Table 3. Perception of usefulness of the haptic simulator among undergraduate Stomatology students.

Perception of usefulness of haptic simulators	Md	P25	P75
P1. To what extent is the haptic virtual simulator useful for self-directed learning in a clinical procedure?	4	4	5
P2. To what extent does the use of the haptic virtual simulator provide manual comfort when performing procedures?	3	3	4
P3. To what extent do the images of the anatomical models and instruments appear realistic?	4	3	4
P4. To what extent is the haptic simulator useful as a tool for evaluating manual dexterity in dentistry?	4	3	4
P5. To what extent is the sensation perceived with the simulator similar to that of a dental handpiece on a real tooth?	4	3	4
P6. To what extent is the sensation perceived with the simulator similar to that of a dental handpiece on an acrylic or ivorine tooth?	4	3	5
P7. What degree of similarity exists between the control of the simulator handpiece and that of a high-speed dental handpiece?	4	3	4
P8. To what extent do you consider that the use of haptic simulators contributes to learning the preparation of a metal-free crown?	4	3	5

Md: median (Q2); P25: 25th percentile (Q1); P75: 75th percentile (Q3); five-point Likert scale (1 = less useful to 5 = very useful).

In contrast, manual comfort during simulator use was the aspect with the lowest score (median = 3), although it maintained a narrow interquartile range, suggesting a consistent perception among participants.

The bivariate analysis revealed statistically significant associations between performance in occlusal reduction and students' perception of similarity between the simulator and a real dental handpiece (p = 0.041), as well as their perception of handpiece control (p = 0.043). Similarly, a significant association was observed between the occlusal convergence angle and the perception of manual comfort during use of the device (p = 0.010). Regarding the association between overall performance (pass/fail) and the perceived usefulness of the simulators, no statistically significant differences were observed (Table 4).

Table 4. Association between clinical performance and dimensions of perceived usefulness of the haptic simulator.

Manual dexterity	Perceived usefulness of haptic simulators															
	P1		P2		P3		P4		P5		P6		P7		P8	
	Md (SD)	p	Md (SD)	p	Md (SD)	p	Md (SD)	p	Md (SD)	p	Md (SD)	p	Md (SD)	p	Md (SD)	p
Occlusal reduction																
Unacceptable	4.00 (1.03)		4.00 (0.70)		4.00 (0.84)		4.00 (0.76)		4.00 (0.96)		4.00 (1.07)		4.00 (0.69)		4.00 (0.88)	
Acceptable	5.00 (0.50)	0.254*	3.00 (1.00)	0.692*	4.50 (0.96)	0.263*	4.00 (0.50)	0.321*	5.00 (0.50)	0.041*	5.00 (0.50)	0.101*	4.50 (0.58)	0.043*	4.50 (0.58)	0.425*
Satisfactory	4.50 (0.96)		3.00 (1.26)		3.00 (1.26)		3.50 (0.96)		3.00 (1.63)		3.50 (1.71)		4.50 (1.89)		3.50 (0.96)	
Axial reduction																
Unacceptable	4.00 (0.58)		3.00 (1.15)		4.00 (1.53)		3.00 (1.15)		4.00 (1.00)		3.00 (1.15)		3.00 (1.15)		3.00 (1.15)	
Acceptable	4.00 (1.08)	0.801*	3.00 (0.77)	0.413*	3.50 (0.99)	0.884*	4.00 (0.81)	0.779*	3.50 (1.25)	0.703*	4.00 (1.25)	0.585*	4.00 (1.09)	0.965*	4.00 (0.84)	0.510*
Satisfactory	4.50 (0.82)		4.00 (0.75)		4.00 (0.52)		4.00 (0.52)		4.00 (0.75)		4.50 (0.98)		4.00 (0.52)		4.50 (0.82)	
Occlusal convergence angle																
Unacceptable	4.00 (1.73)		3.00 (0.50)		2.50 (0.96)		3.50 (0.58)		3.50 (1.41)		3.00 (1.26)		3.00 (1.26)		3.50 (0.58)	
Acceptable	5.00 (0.58)	0.457*	5.00 (0.58)	0.010*	4.00 (0.58)	0.086*	4.00 (0.58)	0.257*	5.00 (1.15)	0.371*	5.00 (0.58)	0.086*	4.00 (0.58)	0.103*	5.00 (0.58)	0.156*
Satisfactory	4.00 (0.81)		3.00 (0.69)		4.00 (0.88)		4.00 (0.80)		4.00 (1.05)		4.00 (1.12)		4.00 (0.86)		4.00 (0.89)	
Location of cervical finish line																
Unacceptable	4.00 (0.76)		3.00 (0.95)		3.00 (1.27)		3.00 (0.98)		4.00 (1.70)		3.00 (1.63)		4.00 (1.38)		4.00 (0.90)	
Acceptable	4.00 (1.12)	0.605*	3.00 (0.82)	0.509*	3.50 (0.81)	0.240*	4.00 (0.68)	0.200*	4.00 (0.93)	0.859*	4.00 (0.89)	0.297*	4.00 (0.86)	0.808*	4.00 (0.89)	0.458*
Satisfactory	4.50 (0.58)		4.00 (0.50)		4.00 (0.50)		4.00 (0.50)		3.50 (0.58)		3.50 (0.96)		4.00 (0.50)		4.50 (0.58)	

P1–P8: correspond to the dimensions of perceived usefulness of haptic simulators described in Table 3; NR: not performed, as students only obtained the "unacceptable" rating.
* Kruskal–Wallis test.
**Mann-Witney U test.

Table 4. (*Continuation*).

Manual dexterity	Perceived usefulness of haptic simulators															
	P1		P2		P3		P4		P5		P6		P7		P8	
	Md (SD)	p	Md (SD)	p	Md (SD)	p	Md (SD)	p	Md (SD)	p	Md (SD)	p	Md (SD)	p	Md (SD)	p
Type of cervical finish line																
Unacceptable	4.00 (0.76)		300 (0.95)		3.00 (1.11)		4.00 (0.98)		4.00 (1.46)		3.00 (1.40)		4.00 (0.98)		4.00 (1.00)	
Acceptable	4.00 (1.13)	0.525*	3.00 (0.82)	0.635*	4.00 (0.94)	0.233*	4.00 (0.70)	0.196*	4.00 (1.06)	0.387*	4.00 (1.15)	0.782*	4.00 (1.03)	0.722*	4.00 (0.83)	0.676*
Satisfactory	4.00 (0.84)		4.00 (0.55)		3.00 (0.45)		3.00 (0.55)		3.00 (0.84)		3.00 (1.10)		4.00 (0.89)		4.00 (0.84)	
Preservation of adjacent teeth																
Unacceptable	4.00 (0.97)		3.00 (0.80)		4.00 (0.93)		4.00 (0.76)		4.00 (1.12)		4.00 (1.17)		4.00 (0.97)		4.00 (0.85)	
Acceptable	-	NR	-	NR	-	NR.	-	NR	-	NR	-	NR	-	NR	-	NR
Satisfactory	-		-		-		-		-		-		-		-	
Condition																
Pass	4.00 (0.71)		3.00 (0.73)		4.00 (0.71)		4.00 (0.60)		4.00 (0.78)		4.00 (0.83)		4.00 (0.78)		4.00 (0.67)	
Fail	4.00 (1.08)	0.561**	3.00 (0.86)	0.820**	4.00 (1.04)	0.781**	4.00 (0.84)	0.631**	3.50 (1.25)	0.463**	3.50 (1.25)	0.131**	4.00 (0.98)	0.095**	4.00 (0.94)	0.527**
Total	4.00 (0.97)		3.00 (0.80)		4.00 (0.93)		4.00 (0.76)		4.00 (1.12)		4.00 (1.17)		4.00 (0.97)		4.00 (0.85)	

P1–P8: correspond to the dimensions of perceived usefulness of haptic simulators described in Table 3; NR: not performed, as students only obtained the "unacceptable" rating.
* Kruskal–Wallis test.
**Mann-Witney U test.

DISCUSSION

Dental education requires the progressive development of skills to perform clinical procedures of varying complexity, including tooth preparation of metal-free crowns, which demands precision in reduction, an appropriate convergence angle, and preservation of adjacent structures. Due to these technical requirements, this procedure constitutes a relevant model for evaluating preclinical performance. In this context, the incorporation of safe training strategies, such as haptic simulation, is particularly relevant to facilitate the progressive acquisition of these competencies before interacting with patients (14).

The present study found a predominantly unfavorable overall performance, as 66.67% of students failed. This finding is consistent with that reported by Stoilov et al. (15), who documented high failure rates in tooth preparations performed using virtual simulators. Taken together, these results suggest that the incorporation of haptic simulators alone does not guarantee the immediate development of technical competence.

Parameter-based evaluation revealed marked differences. Occlusal reduction showed 70.37% of non-acceptable results, consistent with the findings of Hey et al. (16), who reported a tendency toward excessive tooth reduction in virtual simulation. This performance may be explained by limited tactile fidelity and reduced stereoscopic perception compared with conventional simulators, making precise control of reduction more difficult (10,15,16), particularly during the initial phases of training.

The most critical finding was the preservation of adjacent teeth, as 100% of students caused some degree of damage. This result exceeds that described by Habib (12), who reported an average performance of 66.9% for this parameter, and by Hey et al. (16), in whose study 58.33% of students affected up to four adjacent teeth. From a clinical perspective, this is particularly relevant due to the irreversible nature of damage to healthy dental structures (8,16).

The poor performance may be related to an insufficient learning curve, limited training time, and the absence of protective mechanisms within the virtual environment. Although students had prior experience with haptic simulators, the specific practice for metal-free crowns was brief, which likely prevented consolidation of the required skill (17,18). The literature indicates that skill development through these systems requires between three and ten sessions (19) or at least eight hours of structured practice (20), in addition to timely feedback and integration with theoretical foundations (12,15,19)—conditions that were not fully met in this study.

In contrast, the convergence angle showed the best performance, with 74.07% of preparations rated as satisfactory. This finding is consistent with that reported by Amine et al. (20), who found that 74.3% of tooth preparations were within an acceptable range of 6° to 16°, with a mean value of 11.31°. Similarly, Hadjichristou et al. (18) reported a mean convergence angle of 9.45° in the mesiodistal view and 11.23° in the buccolingual view (13), values considered clinically acceptable.

In the same way, axial reduction and the finish line achieved predominantly acceptable levels. This differs from the findings of Hattori et al. (10), who reported less favorable results. This discrepancy may be attributed to the fact that these parameters primarily require visual control rather than tactile feedback; therefore, the simulator's three-dimensional rotation and magnification functions may have partially compensated for haptic limitations. However, there is debate over whether these technological aids reduce clinical realism or enhance learning (15,21).

A relevant finding was the discrepancy between suboptimal technical performance and positive perceptions of the simulator. Students rated its usefulness, similarity to a real dental handpiece, and contribution to self-directed learning favorably, consistent with previous studies reporting high levels of satisfaction and perceived realism in the use of haptic simulators (21–24). These studies consider such systems a useful complement to traditional preclinical training and a valuable tool for self-assessment of manual dexterity (12,20,25,26). However, other authors have highlighted limitations in tactile fidelity (26), demonstrating that user experience varies depending on the context and simulator model employed.

Bivariate analysis revealed statistically significant associations between student performance in occlusal reduction and both the perceived similarity of the simulator to a real dental handpiece ($p = 0.041$) and perceived handpiece control ($p = 0.043$). This suggests that students who perceived greater simulator fidelity and better handpiece control achieved higher scores for this parameter. However, when contrasted with the descriptive analysis, occlusal reduction still demonstrated a high proportion of unacceptable ratings, so this association does not necessarily indicate adequate performance.

Furthermore, an association was identified between performance in convergence angle and perceived manual comfort ($p = 0.010$), suggesting that greater perceived ergonomics facilitated control over reduction during tooth preparation. Simulator functions such as magnification and 360° rotation may have influenced this perception of comfort. In this regard, some studies report that students often prefer practice in this environment because of these features (21,27).

On the other hand, no statistically significant associations were found between overall performance and any of the eight dimensions of perceived usefulness; in other words, such perception did not discriminate between students who passed and those who failed. In this regard, studies such as that by Casallas-Hernández et al. (28) argue that students positively value the usefulness and ease of use of technology, thereby facilitating its incorporation into learning. Nevertheless, these findings confirm that a positive attitude toward simulators may be based more on students' affinity for technology, and that this perception alone is insufficient for the immediate acquisition of clinical competence. This reinforces the need to complement subjective perceptions with objective performance assessments and to integrate simulation into progressive, structured training with continuous feedback (12,15,29).

Study limitations include its cross-sectional design, which precludes evaluation of performance over time, and the reduced sample size, which limits the generalizability of findings. Similarly, although instrument reliability was acceptable and rater calibration was performed, the inter-rater agreement index was not calculated. The fact that the selection of the evaluated tooth preparation was based on student judgment may also have introduced bias. These limitations should be considered when interpreting the results and highlighting the need to strengthen these aspects in future research.

In summary, the findings support the use of haptic simulators in dental education, provided that their incorporation is planned, progressive, and complemented with other simulation strategies and structured faculty feedback. Their effectiveness depends on appropriate pedagogical integration within the curriculum.

CONCLUSIONS

Undergraduate students demonstrated suboptimal performance in tooth preparation of metal-free crowns using haptic simulation, particularly in terms of occlusal reduction and the preservation of adjacent teeth. In contrast, parameters such as convergence angle, axial reduction, and cervical finish line were predominantly acceptable, suggesting that certain aspects of tooth preparation are easier to perform in this virtual environment.

Despite students' positive perception of the simulator's usefulness and tactile realism, a discrepancy was observed in their technical performance; this indicates that subjective evaluation does not guarantee the immediate acquisition of manual dexterity. The significant associations identified between performance in certain parameters and the perception of handpiece control, manual comfort, and similarity to a real dental turbine highlight that the quality of the haptic experience directly influences technical execution.

These findings suggest that haptic simulators may constitute a valuable complement in preclinical dental education if integrated in a structured manner through progressive training sessions, faculty feedback, and practice on phantom heads. Therefore, careful pedagogical planning and adequate training are essential to optimize the development of students' manual and motor skills.

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APPO, DVAP: conceptualization, visualization, methodology, research, writing of the original draft. **ACML:** conceptualization, visualization, methodology, research. **PACA:** conceptualization, visualization, methodology, review. **MIFN:** visualization, research, review, editing.

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REFERENCES

1. Annamma LM, Varma S, Abuttayem H, et al. Current challenges in dental education- a scoping review. BMC Med Educ. 2024;24(1):1523. doi:10.1186/s12909-024-06545-1
2. Sohail FA, Iqbal M, Malik MG, et al. Perspectives of faculty, students and patients on clinical skills teaching in undergraduate medical education in Pakistan: a qualitative study. BMJ Open. 2025;15(11):e103139. doi:10.1136/bmjopen-2025-103139
3. Kızılırmak B, Gözen M, Güntekin N. Evaluation of dental students' tooth preparation skills using conventional phantom labs versus advanced simulation technologies: a comparative study. BMC Med Educ. 2025;25(1):1365. doi:10.1186/s12909-025-08020-x

4. Felszeghy S, Huhtela O, Manninen K, et al. VR-haptic and phantom head dental training: does the order matter? A comparative study from a preclinical fixed prosthodontics course. Int J Comput Dent. 2024;27(4):389-99. doi:10.3290/j.ijcd.b4451364
5. Grandez KE. [Simulators in dentistry and clinical skill training: a permanent dialogue]. Odontol Sanmarquina. 2021;24(3):261-7. doi:10.15381/os.v24i3.20717 Spanish.
6. Liu L, Zhou R, Yuan S, et al. Simulation training for ceramic crown preparation in the dental setting using a virtual educational system. Eur J Dent Educ. 2019;24(2):199-206. doi:10.1111/eje.12485
7. Urbankova A, Palomo L, Engebretson SP. A complex haptic exercise to predict pre-clinic operative dentistry performance: a prospective study. J Dent Educ. 2022;86(12):1628-33. doi:10.1002/jdd.13082
8. Bandiaky ON, Lopez S, Hamon L, et al. Impact of haptic simulators in preclinical dental education: a systematic review. J Dent Educ. 2024;88(3):366-79. doi:10.1002/jdd.13426
9. Wei Y, Peng Z. Application of Simodont virtual simulation system for preclinical teaching of access and coronal cavity preparation. PLoS ONE. 2024;19(12):e0315732. doi:10.1371/journal.pone.0315732
10. Hattori A, Tonami K, Tsuruta J, et al. Effect of the haptic 3D virtual reality dental training simulator on assessment of tooth preparation. J Dent Sci. 2022;17(1):514-20. doi:10.1016/j.jds.2021.06.022
11. Almeida MR, de Melo E. [Dental ceramic system: a literature review]. J Multidiscip Dent. 2024;14(1):54-62. doi:10.46875/jmd.v14i1.1050 Portuguese.
12. Habib SR. Rubric system for evaluation of crown preparation performed by dental students. Eur J Dent Educ. 2018;22(3):e506-13. doi:10.1111/eje.12333
13. Fernández-Sagredo M, Barrios-Penna C, Torres-Martínez P, et al. [Usefulness perception of the haptic virtual simulators in dental education by students, practitioners and academics –a descriptive observational study]. FEM. 2020;23(2):89-94. doi:10.33588/fem.232.1045 Spanish.
14. Patil S, Bhandi S, Awan KH, et al. Effectiveness of haptic feedback devices in preclinical training of dental students - A systematic review. BMC Oral Health. 2023;23(1):739. doi:10.1186/s12903-023-03410-3
15. Stoilov L, Stephan F, Stark H, et al. Efficacy of virtual preparation simulators compared to traditional preparations on phantom heads. Dent J. 2024;12(8):259. doi:10.3390/dj12080259
16. Hey J, Schweyen R, Kupfer P, et al. Influence of preparation design on the quality of tooth preparation in preclinical dental education. J Dent Sci. 2017;12(1):27-32. doi:10.1016/j.jds.2016.05.002
17. Vincent M, Giess R, Balthazard R, et al. Virtual aids and students' performance with haptic simulation in implantology. J Dent Educ. 2022;86(8):1015-22. doi:10.1002/jdd.12916
18. Hadjichristou C, Kokoti M, Bakopoulou A. Haptics in fixed prosthodontics and their role in dental education: a literature review. J Dent Educ. 2024;88(8):1020-8. doi:10.1002/jdd.13533
19. Rodrigues P, Nicolau F, Norte M, et al. Preclinical dental students self-assessment of an improved operative dentistry virtual reality simulator with haptic feedback. Sci Rep. 2023;13:2823. doi:10.1038/s41598-023-29537-5
20. Amine M, Wahid HO, Fahi S, et al. Assessment of convergence angle of tooth preparations for complete crowns among dental students: typodont vs simulator. Int J Dent. 2022;2022(1):7615892. doi:10.1155/2022/7615892
21. Arora O, Sivaswamy V, Ahmed N, et al. Effectiveness of digital visualization in teaching crown preparation to predoctoral dental students - a pilot study. J Popul Ther Clin Pharmacol. 2023;30(12):e168-73. doi:10.47750/jptcp.2023.30.12.019
22. Saravia-Rojas M, Mendiola-Aquino C, Geng-Vivanco R. Virtual haptic reality: a teaching strategy to achieve significant learning in dentistry. Can J Educ Soc Stud. 2023;3(3):46-52. doi:10.53103/cjess.v3i3.142
23. Chávez-Alayo P, Fukuhara-Nakama M, Fernández-Jacinto L. [Previous odontological practice of a clinical case in haptic simulation prior to patient treatment]. Rev Estomatol Herediana. 2024;34(2):191-4. doi:10.20453/reh.v34i2.5537 Spanish.
24. Gramatges-Rojas A, Sittoni-Pino MF, Flacco N, et al. Can haptic reinforced VR simulation transform preclinical pulpotomy training? Insights into skill acquisition, student perceptions, and educational impact: randomized controlled trial. Front Oral Health. 2025;6:1677056. doi:10.3389/froh.2025.1677056
25. San Diego JP, Newton TJ, Sagoo AK, et al. Learning clinical skills using haptic vs. phantom head dental chair simulators in removal of artificial caries: cluster-randomized trials with two cohorts' cavity preparation. Dent J. 2022;10(11):198. doi:10.3390/dj10110198
26. Leung AL, Yeung C, Chu S, et al. Use of computer simulation in dental training with special reference to simodont. Dent J. 2021;9(11):125. doi:10.3390/dj9110125
27. Farag A, Hashem D. Impact of the haptic virtual reality simulator on dental students' psychomotor skills in preclinical operative dentistry. Clin Pract. 2021;12(1):17-26. doi:10.3390/clinpract12010003
28. Casallas-Hernández N, Castillo-Daza CA, González-Guzmán VA. Acceptance and effectiveness of high-fidelity simulation in nursing education: application of the Technology Acceptance Model (TAM).

Clin Simul Nurs. 2025;105:101765. doi:10.1016/j.ecns.2025.101765

29. Urbankova A. Impact of computerized dental simulation training on preclinical operative dentistry examination scores. J Dent Educ. 2010;74(4):402-9. doi:10.1002/j.0022-0337.2010.74.4.tb04885.x