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Impact of haptic simulators in preclinical dental education: A systematic review

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Abstract

Background: Haptic technologies have opened a new avenue in preclinical dental education, with evidence that they can be used to improve student performance. The aim of this systematic review was to (1) determine the effect of haptic simulators on motor skill acquisition during preclinical dental training, (2) explore students' perception, and (3) explore the ability of haptic systems to distinguish users based on their initial level of manual dexterity.

Methods: A comprehensive search of articles published up to February 2023 was performed using five databases (i.e., PubMed/Medline, ScienceDirect, Web of Sciences, Scopus, and Cochrane Library) and specialized journals. The Preferred Reporting Items for Systematic Review and Meta-Analysis 2020 guidelines were followed, and the risk of bias was assessed. Only studies on the application of haptic simulators in dentistry preclinical training were included. Qualitative synthesis of data was performed, and the protocol was registered in PROSPERO (ID = CRD42022337177).

Results: Twenty-three clinical studies, including 1303 participants, were included. The authors observed a statistically significant improvement in dental students' motor skills in various dental specialties, such as restorative dentistry, pediatric, prosthodontics, periodontics, implantology, and dental surgery, after haptic training. Haptic technologies were perceived well by all participants, with encouraging data regarding their ability to differentiate users according to their initial level of manual dexterity.

Conclusions: Our work suggests that haptic simulators can significantly improve motor skill acquisition in preclinical dental training. This new digital technology, which was well perceived by the participants, also showed encouraging results in discriminating users according to their level of experience.

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KEYWORDS

augmented reality, dental, education, haptic feedback technologies, haptic perception technologies, immersive virtual reality, motor performance, motor skills, student perception

1 | INTRODUCTION

Preclinical dental education enables students to acquire various motor skills before they “interact with” and “care for” patients.^{1,2} During this time period, students train on conventional simulators,¹ with which they learn to perform various well-codified technical procedures with dental instruments. Since 1894, these simulators have become a cornerstone of dental education.^{1,3} Indeed, although they have limitations,^{1,4–7} conventional simulators have been used to recreate simulation conditions for a wide variety of dental procedures and thus prepare students for the clinical practice.

Nowadays a complementary approach to conventional simulations based on the use of haptic and force feedback technology has been introduced in the field of dental education to assist or replace traditional methods of teaching clinical skills.⁸ By using virtual or augmented reality environments modeling clinical situations, haptic simulators aim to provide realistic, visual, audio, and tactile sensations thanks to their computer application interface.² This is a relatively new educational approach that has several advantages.^{1,9–11} Simulators that have incorporated this novel digital technology can graphically and haptically simulate real-world clinical situations to improve fine motor skill acquisition.^{1,9,10–18} Unlike conventional simulation, haptic simulators allow for an objective assessment and encourage a self-assessment approach to enhance students’ autonomy. The use of haptic simulators in the early phases of preclinical dental training can improve student performance¹⁹ and accuracy in implant drilling,¹¹ and also provide unlimited training hours.^{1,20} Compelling pedagogical results on dental haptic simulators were also reported in other studies.^{8,21,22} However, Koo et al.²³ concluded that there was no improvement in manual dexterity with haptic exercises.²³ Other authors, such as Moussa et al., evaluated the pedagogical effectiveness of virtual/augmented reality and haptic technologies in dental education in their systematic review and concluded that virtual technology appears to improve education outcomes.⁸ Therefore, this systematic review addresses virtual and augmented reality simulators in dentistry, with haptic properties, referred to by term “haptic simulator” in the rest of this paper. Indeed, there is a lack of systematic reviews that focus solely on the use of haptic simulators in preclinical dental training, which provide clear scientific evidence on their educational contributions in dental education. This systematic review aims to assess the impact of haptic simulators on

preclinical dental education in terms of skill acquisition, their ability to discriminate the users according to the initial level of their manual dexterity as well as to determine the learners’ perception regarding the use of these new digital technologies.

2 | METHOD

The protocol of this systematic review was saved in the PROSPERO database under “ID = CRD42022337177.” The Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) 2020 guidelines²⁴ were applied, and the checklist provided by Page et al. was completed and provided as Supporting Information (Table S1).²⁵ The PICOS (Population, Intervention, Comparison, Outcomes, and Study) design structure was used to define the eligibility criteria of the articles.²⁶ Studies that met the criteria below were included.

Population (P): dental students enrolled in a traditional program of motor skills teaching in preclinical dental training. Intervention (I): the use of haptic simulators in an educational program for dentistry students. Comparison (C): we will compare the differences in motor skills obtained by dental students between the test (only haptic simulators or associated haptic and conventional simulators) and control groups (only conventional simulators) before and after haptic training. Outcomes (O): the primary outcome was the pedagogical value of haptic simulators in terms of motor skill acquisition in preclinical dentistry. The secondary objective was to evaluate the participants’ perception of using the haptic simulators and the ability of haptic technologies to discern the users according to the initial level of their manual dexterity. Study design (S): comparative, crossover, and randomized controlled clinical studies were exclusively included. Articles with no available data, studies dealing only with virtual reality or augmented reality, meta-analyses or literature reviews and all works using haptic simulations in non-dental application domains were excluded.

For the identification of potentially relevant studies, a comprehensive search was conducted using five databases (i.e., PubMed/Medline, ScienceDirect, Web of Sciences, Scopus, and Cochrane Library), as shown in Table 1. A literature search with no date or language limitation was conducted until February 2023. An additional search was performed in the following academic journals (i.e., Journal of Dental Education, European Journal of Dentistry,

TABLE 1 Databases and appropriate search terms.

PubMed/Medline (filters: clinical trial, randomized controlled trial)	("Computer Simulation" [Mesh] OR Simulation, Computer OR Augmented Reality OR Haptic Technology OR Simulation, In silico OR Models, Computer OR haptics-based dental simulator [tiab] OR "Simulation Training" [Mesh] OR "User-Computer Interface" [Mesh] OR "Feedback" [Mesh] OR Touch Perception" [Mesh] OR haptics dental simulators [tiab]) AND ("Academic Performance" [Mesh] OR Performances, Academic OR Performance, Academic Test OR Performance, Educational Test OR Scores, Educational Test OR Score, Academic Test OR "Educational Measurement" [Mesh] OR Educational Assessment OR Assessments, Educational OR Examinations, Graduate Records OR "Education, Dental" [Mesh]) AND ("Psychomotor Performance" [Mesh] OR Sensory Motor Performances OR Performances, Perceptual Motor OR Psychomotor, Performances OR Performance, Perceptual Motor OR "Motor Skills" [Mesh] OR Skills, Motor) AND ("Students, Dental" [Mesh] OR Dental Student OR student discrimination [tiab] OR dental student perception [tiab] OR dental students identification [tiab] OR dental students' performance [tiab] OR preclinical dental training [tiab])
Cochrane Library (filters: title abstract keyword)	Psychomotor skills acquisition OR fine motor skills OR motor skills OR clinical competence OR academic performance OR preclinical training AND dental education OR dental students OR dental student perception OR dental student identification OR preclinical dental training AND haptics dental simulators OR haptics-based dental simulator OR virtual reality OR simulation OR dental simulation OR haptics OR force feedback
Web of Sciences (all fields)	(Psychomotor skills acquisition OR fine motor skills OR motor skills OR clinical competence OR academic performance OR preclinical training) AND (dental education OR dental students OR dental student perception OR dental student identification OR preclinical dental training) AND (haptics dental simulators OR haptics-based dental simulator OR virtual reality OR simulation OR dental simulation OR haptics OR force feedback)
Scopus (all fields)	Psychomotor skills acquisition OR dental education OR dental student perception OR dental student psychomotor skills acquisition OR fine motor skills OR motor skills OR clinical competence OR academic performance OR preclinical training AND dental education OR dental students OR dental student perception OR dental student identification OR preclinical dental training AND haptics dental simulators OR haptics-based dental simulator OR virtual reality OR simulation OR dental simulation OR haptics OR force feedback
ScienceDirect (filters: research articles)	1#: (Psychomotor skills acquisition OR fine motor skills OR motor skills OR clinical competence AND dental education OR dental students OR dental student perception OR dental student identification) 2#: (academic performance OR preclinical training OR preclinical dental training AND haptics dental simulators OR haptics-based dental simulator OR dental simulation OR haptics OR force feedback)

Journal of Surgical Education, Journal of Frontiers in Robotics and AI, Journal of Dentistry, International Journal of Environmental Research and Public Health, Journal of Clinics and Practice, European Journal of Dental Education, International Journal of Paediatric Dentistry) and in all the references of the eligible articles.

The studies identified in various databases and specialized journals were screened by one author (O.N.B.) and verified by another (L.L.). The citations of the listed articles were imported into Mendeley. In this software, duplicates were removed, and the titles and abstracts were read to exclude irrelevant articles. The texts of eligible articles were read in their entirety to retain only those that met the inclusion criteria.

The data retrieval and synthesis were performed using Microsoft Excel by O.N.B. and validated by L.L. An Excel file was created to collect the demographic data (i.e., name of first author, year and country of publication, number of participants, mean age, and level of education), study methodology (i.e., study design, the haptic simulator used,

performed scenarios, number of training sessions, dental specialty, user perception, and assessed variables), and main results. The corresponding authors were contacted by email in the case of missing data. If no response was received after three attempts, the article was excluded from the synthesis of the results.

The risk of bias was assessed for all included studies according to the basic criteria proposed by the Cochrane Handbook for randomized controlled trials.²⁷ For non-randomized studies, the risk of bias was assessed according to the method proposed by Tsirogiannis et al.²⁸

For motor skill acquisition, we performed a qualitative synthesis of the data by grouping the studies by dental specialties. The studies on participants' perception and the ability of haptic simulators to discriminate the user level were grouped for each of these parameters. The quantitative synthesis (meta-analysis) was not considered appropriate because of the wide variability of the study designs, populations, simulators, and types of interventions.

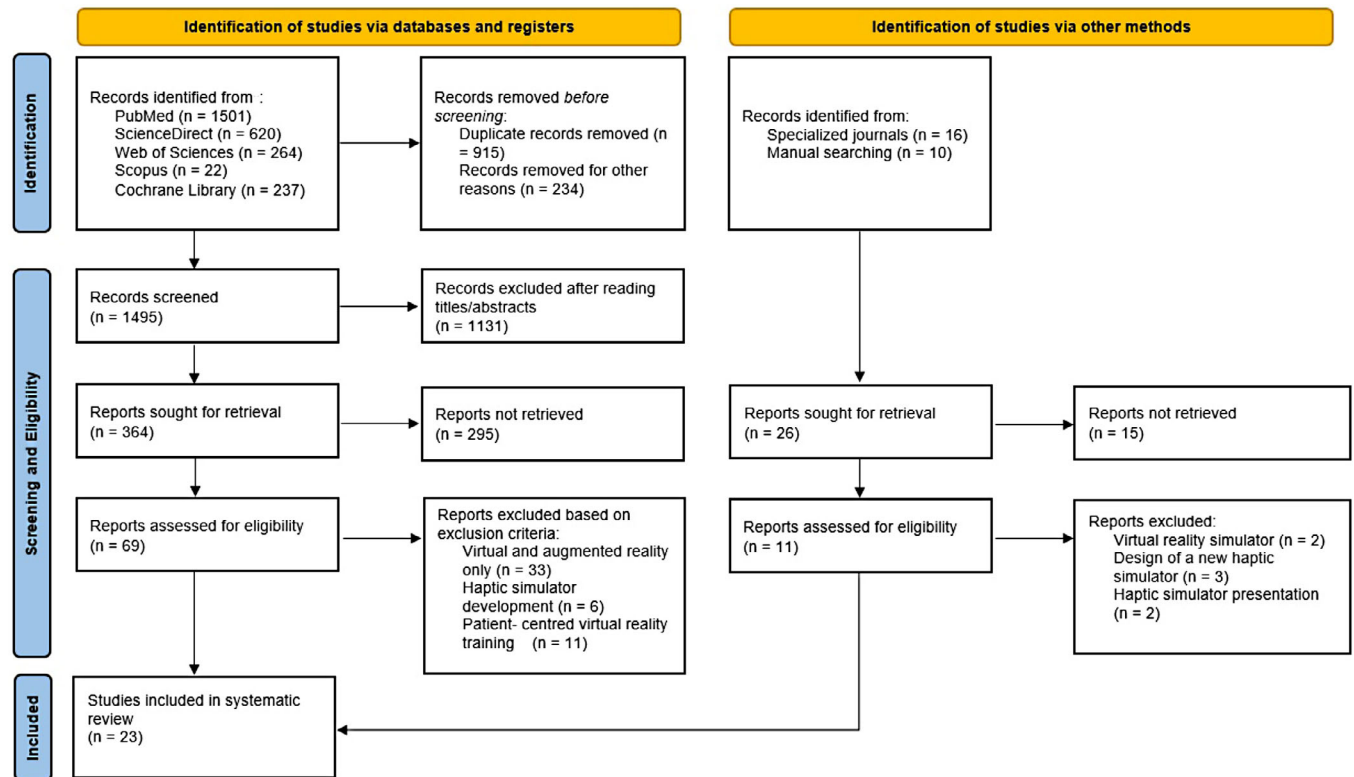


FIGURE 1 The Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) flow diagram of the current systematic review.²⁵

3 | RESULTS

A total of 2670 articles were identified, and only 23 studies met the inclusion and exclusion criteria. Figure 1 describes the different stages of article selection according to the PRISMA 2020 guidelines and the reasons for the article exclusion. The characteristics of the included studies are presented in Table 2. In summary, there were eight comparative trials,^{16,21,29–34} three cross-sectional trials,^{14,35,36} six randomized controlled studies,^{11,23,37–40} five comparative crossover studies,^{13,18,41–43} and one retrospective cohort study.⁴⁴ A total of 1303 participants aged 18–35 years were included, the majority being first-year dental students. Six types of dental haptic simulators were used in these studies (Table 2): IDEA (DEA, Inc.), VirTeaSy (VirTeaSy, HRV Simulation, Laval, Pays De La Loire), Simodont Dental Trainer (Moog Industrial Group, Nieuw-Vennep), VIDA Odonto (INTERLAB), UniDental (Zhonghui Technology Institute, UniDental-MS01), and HVRS (SensAble Inc.). The scenarios varied between studies and included amalgam cavity preparation, implant site drilling, locoregional anesthesia, periodontal debridement, and crown support tooth preparation.

3.1 | Motor skill acquisition

Student performance, as defined by the acquisition of motor skills in different tasks, was evaluated in 11 studies across different dental specialties. In restorative dentistry, six studies evaluated the impact of haptic simulations alone or in combination with conventional simulations on student performance.^{13,23,29,38,39,41} The results of five studies showed that haptic simulators significantly improved learners' educational outcomes in terms of reduced work time and better Class 1 cavity quality.^{13,29,38,39,41} Only one study did not show a significant impact of haptic training on the quality of Class II amalgam and Class III resin preparation, but the authors reported that students who completed the haptic exercises had statistically significant higher scores in the treatment of the adjacent plastic tooth.²³ Some authors studied the effects of different types of pedagogical feedback on the gained motor skills and the transfer of these skills into the real preclinical setting.^{39,41} With 63 participants, Al-Saud et al. showed that the combined feedback from the simulator and instructor resulted in better performances compared to the simulator or instructor feedback alone.³⁹ In the same dynamic, de Boer

TABLE 2 Characteristics of the included studies in all dental specialties.

Author, year, country	Study design	Participant (n)	Haptic simulators	Dental specialty (assessed task)	Assessed outcomes	Findings
Urbankova et al., ³⁵ 2022, USA	CST	1st-year DS (39)	IDEA (VR haptic simulator)	Restorative dentistry (Black's ClassII CP)	Students' performances and discrimination of student levels	A complex manual dexterity test on a haptic simulator given to novice dental students was predictive of early preclinical success.
Ziane-Casenave et al., ¹⁶ 2022, France	CT	Non-dentists (12), 1st-year DS (10), 3rd-year DS (12), final-year DS (11), RG (11)	VirTeaSy (VR haptic simulator with or without immersive environment)	Restorative dentistry (Black's Class I CP)	Students' perception and discrimination of student levels	No significant differences between the groups for the first attempt, manual ability tests performed on the simulator did not discriminate between students based on their level of expertise.
Vincent et al., ¹¹ 2022, France	RCT	1st-year DS (88)	VirTeaSy (VR haptic simulator with or without immersive environment)	Implantology (implant drilling site)	Students' performances	The association of simulator assistance and gesture repetition allows the student to acquire more quickly the skills to perform his clinical gestures in real conditions.
Hattori et al., ¹⁸ 2022, Japan	CCO	6th-year DS (30)	Simodont (AR haptic simulator)	Prosthodontics (tooth full-contour preparation)	Students' performances	Using a different simulator affected subject performances for margin design and total cut volume. A better preparation quality was achieved with a haptic simulator.
Farag and Hashem, ¹³ 2021, Saudi Arabia	CCO	3rd-year DS (21)	Simodont (AR haptic simulator)	Restorative dentistry (Black's Class I CP)	Students' performances	Significant time reduction and overall significant improved performances in psychomotor skills was found after HVRS training.
Collaço et al., ²¹ 2021, Brazil	CT	Clinical DS (163)	VIDA Odonto (IVR haptic simulator)	Oral surgery (inferior alveolar dental anesthesia)	Students' performances and perception	HVR immersion improves the technical skills needed to perform inferior alveolar dental anesthesia with a greater accuracy and confidence.

(Continues)

TABLE 2 (Continued)

Author, year, country	Study design	Participant (n)	Haptic simulators	Dental specialty (assessed task)	Assessed outcomes	Findings
Zhang et al., ³⁷ 2021, China	RCT	2nd, 3rd-year DS (60)	UniDental (VR simulation platform)	Periodontology (supragingival scaling)	Students' performances	The combination of virtual reality and jaw model during periodontal preclinical training improves acquiring of students' professional skills.
Murbay et al., ²⁹ 2020, China	CT	2nd-year DS (32)	Simodont (AR haptic simulator)	Restorative dentistry (SISTA classification site 1 CP)	Students' performances	The number of students who performed satisfactory preparations was greater in group exposed to the Simodont (12/16) than the group with no exposure to VR (7/16). The use of HVRS significantly improved the performance of students.
Vincent et al., ³⁸ 2020, France	RCT	1st-year DS (88)	VirTeaSy (VR haptic simulator with or without immersive environment)	Restorative dentistry (Black's Class II CP)	Students' performances	No significant difference between haptic and conventional simulator groups in terms of psychomotor skills acquisition.
Zafar et al., ³⁶ 2020, Australia	CST	NR (100)	Simodont (AR haptic simulator)	Pediatric (pulpotomies and SSC preparation)	Students' perception	More than 51% of the students said that using Simodont facilitated their learning and understanding of pediatric dentistry tasks, although 88% of them felt that Simodont could not replace the conventional simulator.
Al-Saud et al., ⁴⁴ 2020, UK	RCS	2nd/4th-year DS (72)	Simodont (AR haptic simulator)	Prosthodontics (tooth full-contour preparation)	Students' performances	Students who scored highly on this averaged measure were ~10 times more likely to be high performers in the clinical crown test
Al-Saud et al., ³⁹ 2017, UK	RCT	Non-dentists (63)	Simodont (AR haptic simulator)	Restorative dentistry (five different geometric shapes)	Students' performances	The acquisition and retention of basic dental motor skills in novice students is better optimized through a combination of instructor and visual display (VR)-driven feedback.

(Continues)

TABLE 2 (Continued)

Author, year, country	Study design	Participant (n)	Haptic simulators	Dental specialty (assessed task)	Assessed outcomes	Findings
de Boer et al., ^{41,43} 2017, The Netherlands	CCO	1st-year DS (101)	Simodont (AR haptic simulator)	Restorative dentistry (cross figure preparation)	Students' performance and satisfaction	Only students with FFB were able to pass the two tests. FFB is important for performances in a VLE and 100% of the students preferred working with FFB.
Koo et al., ²³ 2015, USA	RCT	1st-year DS (34)	IDEA (VR haptic simulator)	Restorative dentistry (Black's Class II, III haptic exercises)	Students' performance and perception	The exercises with the haptic simulator were not superior in improving the manual dexterity of students but made the learning experience more fun and interesting.
Joseph et al., ⁴⁰ 2014, France	RCT	Experienced practitioners (20), 3rd-year DS (40)	VirTeaSy (VR haptic simulator with or without immersive environment)	Implantology (implant drilling site)	Students' performance	The results of the simulator group remain like those of the experienced practitioners. The haptic simulator provides a real benefit in implant surgery training.
Eve et al., ³⁰ 2014, USA	CT	1st-year DS (12), experienced prosthodontics residents (14)	VirTeaSy (VR haptic simulator with or without immersive environment)	Restorative dentistry (removed carious lesion)	Students' performance and discrimination of student levels	The simulator can distinguish performances between users with different levels of preclinical and clinical training.
Suebnumkam et al., ³¹ 2014, Thailand	CT	Novice DS (14), intermediates DS (14), endodontics experts (6)	HVRS (VR haptic simulator)	Restorative dentistry (endodontic CP)	Discrimination of student levels	The haptic VR dental simulator demonstrates its capability to discriminate experts and non-experts.

(Continues)

TABLE 2 (Continued)

Author, year, country	Study design	Participant (n)	Haptic simulators	Dental specialty (assessed task)	Assessed outcomes	Findings
Urbankova et al., ³² 2013, USA	CT	1st-year DS (39)	IDEA (VR haptic simulator)	Restorative dentistry (haptic exercise plastic tooth preparations)	Students' performance and discrimination of student levels	The number of failures during exercise in the haptic environment was found to be a significant predictor of exam performances in the preclinical situation. The simulator would allow the identification of students with manual skill difficulties.
Ben-Gal et al., ³³ 2013, Israel	CT	DS (63), dentists (28), non-dentists (14)	IDEA (VR haptic simulator)	Restorative dentistry (haptic exercises)	Discrimination of student levels	The simulator was able to differentiate between non-professionals and dental students or non-professionals and dentists.
Urbankova and Engbretonson, ⁴² 2011, USA	CCO	1st-year DS (39)	IDEA (VR haptic simulator)	Restorative dentistry (Black's Class II CP haptic exercises)	Discrimination of student levels	The use of haptic technologies allows for the detection of students who may have manual ability difficulties.
Ben-Gal et al., ³⁴ 2011, Israel	CT	Dental educators (21), 5th-year DS (12)	IDEA (VR haptic simulator)	Restorative dentistry (haptic exercises)	Dental educators and student perception	The simulator could provide significant potential benefits in teaching and self-learning of manual dental skills.
Suebunukarn et al., ¹⁴ 2010, Thailand	CST	4th-year DS (20)	HVRS (VR haptic simulator)	Restorative dentistry (endodontic CP)	Students' performance	Significant improvements were observed through training in all variables. The novices could learn to perform opening pulpar chamber faster and with more consistency after haptic training.

Abbreviation: FFB, Force FeedBack; CST, cross sectional trial; CT, comparative trial; RCT: randomized controlled trial; CCO: comparative crossover; RCS, retrospective cohort study; DS, dental students; VR, virtual reality; AR, augmented reality; IVR, immersive virtual reality; HVRS, haptic virtual reality system; HVR, haptic virtual reality; RG, recent graduates; VLE, virtual learning environment; DFB, device feedback; IFB, instructor verbal feedback; IDFB, instructor and device feedback; FFB, force feedback; HS, haptic simulator; CP, cavity preparation; SSC, stainless steel crowns

et al. demonstrated that the performances of students operating with Force FeedBack (FFB) were significantly better than those of students operating without FFB.⁴³ Two studies conducted by the same team evaluated the benefits of a haptic simulation in terms of skill acquisition during an implant placement procedure.^{11,40} In the first study realized by Vincent et al.,¹¹ the authors evaluated the impact of virtual simulation aids on an implant drilling proficiency. Using 88 novice students randomized into two groups (i.e., with/without virtual aids), the authors concluded that virtual aids combined with task repetition facilitate the acquisition of implantology skills. In addition, students acquire more quickly the skills allowing them to carry out these clinical gestures in preclinical conditions. In the second study conducted by Joseph et al., 40 third-year dental students with no knowledge in implantology were involved. Students were split into two groups: 20 beginners and 20 simulator-trained. Those groups were compared with 20 experienced practitioners (i.e., implantology experience >15 implants).⁴⁰ The authors demonstrated that the accuracy in implant drilling of the VirTeaSy simulator-trained group was similar to that of the experienced practitioners.⁴⁰ Other authors, such as Collaço et al., have shown that in oral surgery,²¹ total immersion in haptic simulations improves the motor skills necessary for the accurate realization of locoregional anesthesia. Only one study focused on the use of haptic simulators in periodontology and concluded that the combination of virtual reality and conventional simulations increases student performance and improves the acquisition of professional skills necessary for periodontal debridement.³⁷ Regarding fixed prosthodontics, Hattori et al.¹⁸ compared the average score of the marginal preparation quality of a haptic simulator and a conventional simulator. Thirty sixth-year dental students performed marginal preparations for cast crowns using both simulators. The authors reported that the quality of the preparations was better for students trained with the conventional simulator than those trained with the haptic one. In summary, almost all of the included studies contribute to demonstrating a real interest in haptic simulations in preclinical dental training with encouraging pedagogical results in terms of acquisition and significant improvement of motor skills and transfer under preclinical conditions.

3.2 | Students' perception

Five studies assessed students' perceptions of using haptic simulators with questionnaires.^{21,23,34,36,43} In a sample of 100 students, Zafar et al. reported that half of the participants said the Simodont simulator facilitated their learning and understanding of pediatric dentistry tasks.³⁶ In a study

by Collaço et al., 163 students felt more confident in performing inferior alveolar dental anesthesia after a haptic immersive training.²¹ In a randomized controlled study, Koo et al. concluded that 65% of students in the test group thought that the haptic simulation is more interesting for learning the tasks and makes the learning experience more fun.²³ In a study by de Boer et al.,⁴³ all students preferred working with FFB provided by the haptic simulation over the conventional simulation. All participants in the study of Ben-Gal et al. found that the haptic simulator may have potential benefits for dental education in terms of facilitating the self-study of drilling gestures, and the acquisition of dental manual skills.³⁴ In summary, haptic simulators are very well perceived by all participants in the various included studies.

3.3 | Discrimination of students' level

Eight studies evaluated this discrimination at the student level.^{16,30-33,35,42,44} Some authors, such as Urbankova et al., investigated whether the dental student performance on an haptic simulator during a single 15-min session was associated with the performance assessed during the practical examination of operative dentistry in a preclinical context.³⁵ These authors reported that 23% of students who failed the haptic test seven times had low scores on the first practical assessment. Furthermore, strong associations were observed between success on the haptic test and the early practical examination score.³⁵ The same authors previously reported in 2011 and in 2013 that the number of failures on a haptic exercise was predictive of student performances in examination tasks.^{32,42} The authors of four other studies,^{30,31,33,44} also concluded that the haptic simulator can differentiate users based on their level of manual dexterity according to some haptic dexterity tests. Eve et al. showed that the average performance of novices and experienced participants differed significantly during the exercises in haptic environments.³⁰ In this study, experienced subjects removed a greater portion of the carious lesions. Similarly, in a sample of 106 participants divided into three groups: (1) 63 dental students, (2) 28 dentists, and (3) 14 non-dentists, Ben-Gal et al. demonstrated that the simulator tests differentiated non-professionals from dental students or dentists.³³ These results confirm those of Suebnukarn et al.,³¹ who demonstrated that the haptic simulator was able to distinguish between novice and expert execution of crown preparation tasks.³¹ However, other authors, such as Ziane-Casenave et al.,¹⁶ did not find any difference between the three kinds of participants (i.e., non-dentists, first/third/final-year dental students, recent graduates) because the haptic test (i.e., Black's Class I cavity preparation), in their opinion, was not able to

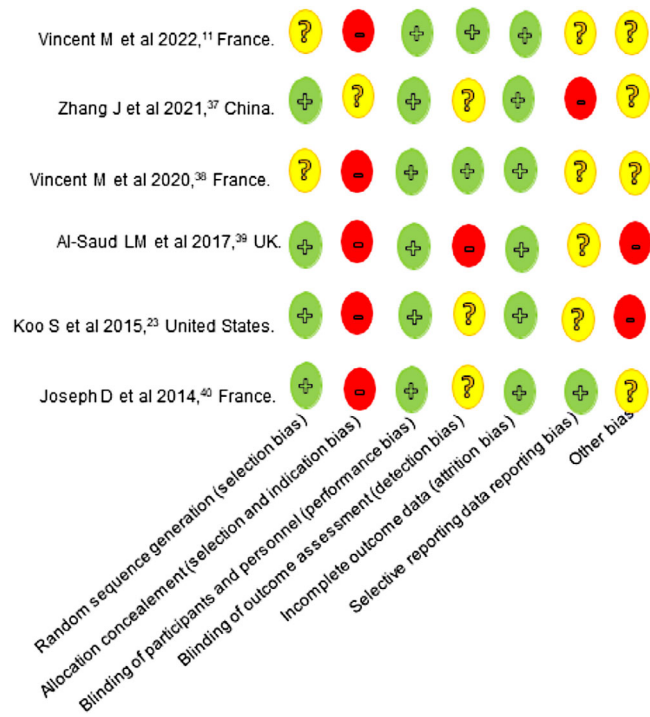


FIGURE 2 Risk of bias of randomized included studies: green indicates low risk of bias, yellow indicates uncertain or moderate risk of bias, and red indicates high risk of bias.

distinguish their initial performance level. Overall, our systematic review shows encouraging results regarding the ability of dental haptic simulators to differentiate users according to their initial manual skills.

All these studies had a low to moderate risk of bias (Figure 2 and Table 3).

4 | DISCUSSION

Haptic technology has been introduced in recent years as a complementary approach to conventional simulations in dental education.¹³ This new digital technology is gaining more and more ground for learning dental gestures and acquiring technical skills in dentistry.¹¹ The objectives of this systematic review were to (1) evaluate the impact of haptic simulators in preclinical dentistry education in terms of motor skill acquisition, (2) determine the learners' perception of the use of those simulators, and (3) determine their ability to discriminate users according to their initial level of manual dexterity. The synthesis of data from the included studies showed that the use of haptic simulators in preclinical dental training significantly improves motor skill acquisition, retention, and transfer in different dental specialties. These FFB-based systems were well perceived by learners and, to some extent, allow teachers to distinguish users based on their initial performance level.

Our results are consistent with those of Haroon et al., who concluded in their narrative review that manikins and virtual/augmented reality simulations along with the haptic technology can be very helpful for skill training.⁴⁵ Based on the results of this systematic review, the effect of haptic simulators on motor skill acquisition was evaluated in five dental specialties.

In restorative dentistry, we have shown that haptic simulators are an interesting pedagogical tool for training novice students. It allows for a faster acquisition and improvement of technical skills, a reduced working time, the ability to self-evaluate, and a better quality of preparations for cavities.^{13,14} The haptic technology allows for similar,³⁸ or significantly better preparations,²⁹ such as Black's Class II or SISTA Site 1, when compared to the conventional simulator. This can be explained by the fact that the standardized feedback with independence from direct supervision or unlimited training hours plays an essential role in achieving a better manual dexterity and gesture accuracy.^{21,43} This result is supported by the team of Al-Saud et al., who demonstrated that participants had better performances and lower errors when they combined simulator feedback with the instructor one.³⁹ Similar results were reported by Rodrigues et al., who concluded that the DENTIFY simulator has the potential to improve learning because it promotes self-evaluation.¹⁷ In implant surgery, two studies^{11,40} reported a significant pedagogical results in terms of progressive reduction of cortical bone perforations and improvement in the implant drilling precision. Therefore, the virtual assistance provided by the haptic simulator provides a real benefit for implant surgery training.¹¹ Other authors, such as Hattori et al.,¹⁸ concluded that the conventional simulator provides a better quality in term of prosthetic preparations.¹⁸ These results are not surprising because, although haptic technology is growing, it still lacks realism in some specific dental specialties, such as prosthodontics. Indeed, there is a big difference in the tactile sensation during the marginal preparation of the teeth between haptic and conventional simulators.¹⁸ The control of rotating instruments is often difficult to simulate with haptic technology. In addition, the lack of support for the adjacent tooth during the preparation makes the task difficult. All these points may justify the discrepancies in observed performances between the two simulators.¹⁸ In addition, in this study, one-fifth of the subjects noted that it was more difficult to grasp the extent of the preparation in the haptic simulator.¹⁸ These results may also be explained by the fact that dental haptic simulators still have many hardware and software disadvantages that have prevented them from being an alternative to traditional dental simulators as a primary skill training method.⁴⁶ As in prosthodontics, there are very few studies on the use of haptic simulators in other specialties such as periodontics

TABLE 3 Modified methodological index assessing level risk bias in non-randomized studies (MINORS, methodological index for non-randomized studies).

	Evaluation score ^a											
	Urbankova et al., 2011, ³² 2022 ³⁵	Ziane-Casenave et al., ¹⁶ 2022	Hattori et al., ¹⁸ 2022	Farag and Hashem, ¹³ 2021	Collaço et al., ²¹ 2021	Murbay et al., ²⁹ 2020	Zafar et al., ³⁶ 2020	Al-Saud et al., ⁴⁴ 2020	de Boer et al., ^{41,43} 2017	Eve et al., ³⁰ 2014	Suebnuakarn et al., 2010, ¹⁴ 2014 ³¹	Ben-Gal et al., 2011, ³⁴ 2013 ³³
Clearly stated purpose	2	2	2	2	2	2	2	2	2	2	2	2
Study design	2	2	2	2	2	2	1	2	2	2	2	2
Randomization	0	0	0	0	0	0	0	0	0	0	0	0
Formation and comparability of groups	2	2	2	2	2	2	0	2	2	2	2	2
Characteristics of the study	2	2	2	2	2	2	2	2	2	2	2	2
Are studied factor(s) studied, or measured parameters are well described?	2	2	2	2	2	2	2	2	2	2	2	2
Primary endpoint	2	2	2	2	2	2	2	2	2	2	2	2
Appropriate sample size	2	1	2	1	2	2	2	2	2	1	1	1
Statistical power and justification of the number of participants	1	1	1	1	2	1	1	1	1	1	1	1
Statistical analysis	2	2	2	2	2	2	2	2	2	2	2	2
Prospective data collection	2	0	0	0	0	0	0	2	0	0	0	0
Follow-up period adapted to the objective of the study	2	0	0	0	0	0	0	2	0	0	0	0
Total score	21	16	17	16	18	17	14	21	17	16	16	16

^aScore attributed—0: not reported, 1: reported but inadequate, 2: reported and adequate.

or oral surgery. The two studies published to date on these two latter specialties reported significant improvements in the technical and professional skills required to perform a supragingival debridement (i.e., supragingival scaling) or a nerve block anesthesia.^{21,37} Almost all the studies in our systematic review agree that a positive impact was demonstrated through a faster acquisition of skills with haptic simulations. This acquisition is facilitated by FFB, the use of virtual aids, or a combination of feedback from haptic simulations and instructors.

The use of haptic and force feedback technology in dental schools is becoming increasingly evident due to its effectiveness in motor skill training. Indeed, a recent bibliometric analysis, realized by Hsu and Chang, predicts a significant increase in the number of publications (e.g., 2001–2010, $n = 13$; 2011–2022, $n = 72$) on haptic technologies used in dental education.⁴⁷ The results of this analysis show that haptic simulators receive special attention for learning manual skills in preclinical dental training. However, the perception of the users regarding these simulators deserves to be evaluated. Concerning this point, our systematic review shows that haptic technologies were well perceived by participants of included studies, who claimed that the use of haptic simulators helped them in knowledge acquisition and facilitated their understanding of the performed task.^{1,23,34,36,43} Concerning the discrimination of the students according to their initial level of manual dexterity, our systematic review shows encouraging results, suggesting that haptic simulators would be able to distinguish users with different manual skill levels.^{30–33,35,42,44} These results provide new perspectives for managers of dental education programs. Indeed, they are now faced with two major challenges: (1) the reduction of the teaching staff and (2) the increase in the number of students entering the first year of dental studies. These two challenges require the implementation of new pedagogical approaches and the diversification of learning styles to guarantee the training quality. In this respect, the use of haptic simulators to stratify students and predict their performances could allow for personalized training and allow students to work at their own pace. In addition, Li et al. report in their literature review that the application of haptic simulators in dental education can also make up for shortcomings of traditional teaching methods and reduce the teaching burden, which is more convenient for teachers and students.⁴⁶ These authors argue that, with the scientific and technological development, haptic simulators that gradually combine big data, cloud computing, 5G, and deep learning technology will provide individualized learning assistance to students, and their functions will be more diverse and suitable for preclinical training.⁴⁶ Indeed, the early identification of students with manual skill difficulties could allow for reinforcement sessions

or the allocation of more instructional resources to those most in need.³² For example, students with low haptic test scores could be encouraged to spend more time practicing with the haptic simulator to improve their skills.³⁵ Therefore, using a manual ability test on haptic simulations to improve the admissions process of students in dental school, or distinguish those who need an additional assistance is becoming increasingly relevant.⁴⁰ To our knowledge, this is the first systematic review that treated the ability of haptic simulators to differentiate between users. The 12-year interval shows the increase in the number of publications in this field and improvements that have been made to the various simulators, thanks to feedback from participants. It would be interesting to study the correlation between the functional evolution for those simulator with the three analysis criteria of this study (i.e., motor skills, student perception, and manual dexterity) to make their design more efficient. Indeed, further development of haptic simulators with improvements in terms of sensory feedback, ergonomics, and evaluation criteria are still necessary as well as some software expansions to increase the number of dental scenarios. Finally, the specificities of augmented reality (i.e., the temporal and spatial synchronization of 3D virtual objects with the real world) simulators must also be deeply investigated and especially compared with VR ones.

However, this study had several limitations. The studies were conducted on several different populations, including volunteers, novice students, non-dentists, and experienced practitioners. The scenarios used to assess motor skill acquisition in haptic training also differed between studies, as the criteria used to assess the quality of preparations in the conventional simulation. To assess the risk of bias, Figure 2 and Table 3 show an overall moderate level of evidence with a low degree of bias in most studies.

5 | CONCLUSION

Despite the limitations of this review, it appears that haptic simulators can significantly improve the acquisition, maintenance, and transfer of motor skills. This new digital technology is well perceived by participants and shows encouraging results regarding its ability to discriminate users based on their initial level of manual dexterity.


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CONFLICT OF INTEREST STATEMENT

The authors declare they have no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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