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The impact of virtual reality haptic simulators in pre-clinical restorative dentistry: a qualitative enquiry into dental students' perceptions

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Abstract

Purpose In the realm of restorative dentistry, the integration of virtual reality haptic simulation (VRHS) for learning operative skills has garnered varied perceptions among dental students. Therefore, the aim of this study was to delve deep into undergraduates dental students' perceptions related to the impact of VRHS in pre-clinical restorative dentistry.

Methods A homogeneous purposive sampling method was utilized to gather data from third-year undergraduate dental students ($n = 23$) at the College of Dental Medicine, Qatar University, to thoroughly investigate their views on the impact of VRHS on their learning experience in preparing a standard class I cavity. An explorative qualitative method using face-to-face focus group sessions were conducted in English during 2023. Focus group sessions were recorded and transcribed using Microsoft Teams. Two authors independently read the transcripts, coded the text, and manually analyzed text using an inductive thematic approach.

Results A total of 21 (91.3%) students participated in this study. Analysis of 3 focus group interviews revealed five primary themes summarized with the term "MASTR" (M = manual dexterity, A = assessment, S = sequence, T = training, and R = realism). Based on frequency of reported themes, students perceived realism/ lifelike nature of VRHS requiring further enhancement to achieve the desired learning objective.

Conclusion Although, VRHS play a crucial role in modern dental education, offering innovative solutions for training, evaluation, and feedback, the need to enhance their ability to simulate real-life dental procedures and learning environment (realism), coupled with interactive and immersive learning experiences were the most frequently raised theme by students. In terms of curriculum design and learning pedagogies, dental educators should consider the appropriate sequence when integrating VRHS within the undergraduate curricula.

Keywords Virtual reality haptic simulator, Dentist, Restorative, Dental education, Curriculum, Psychomotor skills

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Introduction

Simulation has a longstanding history in dental education, dating back to the 1990s. However, recent advancements in robotics, haptics, and virtual reality (VR) have transformed the field, offering a promising future [1]. In dentistry, the challenge of teaching undergraduate dental students the management of dental caries during pre-clinical training has promoted a re-evaluation of traditional methods. Cavity preparation using plastic teeth (typodont teeth) has often been reduced to a mere manual dexterity exercise, potentially reinforcing undesirable habits such as excessive use of high-speed diamond burs. Moreover, this approach may yield inconsistent results [2].

The principal focus of pre-clinical operative dentistry education is on dental students gaining psychomotor skills, which are the core competency and trademark in the field of dentistry. The majority of the pre-clinical teaching hours are assigned to proper these skills [3, 4]. To support the pre-clinical teaching and learning experience, haptic simulators have been introduced in dental education. These simulators enable students to practice essential skills such as hand-eye coordination, manual dexterity, and mirror handling in a controlled, resource-efficient, and safe environment. Additionally, they allow entire student cohorts to undertake identical exercises, making them particularly well-suited for examinations and assessments [2].

Simulation exercises can provide methods of evaluation, validating the assessment of students' potential based on their performance in relation to SMART objectives. This approach corroborates a high-level of consistency and validity, which can be strenuous to attain in a traditional pre-clinical skills laboratory. The progress in haptic technology within the field of dentistry has resulted in notable advancement in dental education and training. Haptic technology encompasses the application of touch feedback for imitating the sensation of touch. As a response to these developments, dental schools worldwide are increasingly integrating virtual reality simulators into pre-clinical training programs. This integration aims to better prepare students for the transition from simulated dental learning environments to actual clinical settings [5].

Haptic integration has found applications in a wide range of medical and dental fields, upgrading the effectiveness of training, diagnostic, and treatment. For example, in the field of surgery, surgical simulators equipped with haptic technology authorize trainees to practice minimally invasive procedures imitating realistic tactile sensation [6]. In the realm of restorative dentistry, the integration of virtual reality haptic simulation (VRHS) for learning operative skills has garnered varied perceptions among dental students. A study by Buchanan revealed that students generally perceive VR simulation as a beneficial tool for enhancing their operative skills, particularly in initial learning stages, due to its ability to provide immediate feedback and a controlled learning environment [7]. However, a significant observation by Li Yet al. indicated that while students value the technical skill development offered by these simulations, they also express concerns about the lack of realism in terms of patient interaction compared to actual clinical scenarios [8]. This sentiment is echoed in research by Murbay et al., where students reported that while VRHS are valuable for practicing procedures, they cannot fully substitute the experience and challenges of working on typodont teeth nor on real patients [9]. These studies suggest that dental students perceive VRHS as a complementary, rather than a replacement tool in acquiring operative skills, emphasizing the necessity of enhanced real-life clinical experience to achieve comprehensive training. Therefore, the aim of this study was to delve deep into dental students' perceptions related to the impact of VRHS in pre-clinical restorative dentistry.

Materials and methods

Ethical approval

This qualitative study sought to assess students' perception, in depth, on the effectiveness of VRHS on their learning experience in preparing a standard class I cavity. Ethical approval was obtained from the Institutional Review Board at Qatar University (QU-IRB 1652 A/22).

Setting

The study was conducted at the College of Dental Medicine, Qatar University. Initially, in year 2, students were trained on using the VRHS (SIMtoCARE Dente®, SD001, Vreeland, The Netherlands) for the purpose of learning dental charting. The VRHS device features high fidelity in a large workspace of 100×100×100 mm. This way the complete upper and lower jaw can be reached without moving the model. Moreover, The SIMtoCARE Dente® uses a 4 K high resolution screen with autostereo technology, enabling the user to visualize in-depth without having to wear 3D glasses. The mixed reality visor integrates the display of both tangible and virtual objects within a unified visual field. Consequently, this technology allows for the concurrent visibility of the practitioner's hands and finger rest, alongside the targeted tooth undergoing operative procedures. Haptic feedback, commonly known as force feedback, is a technological innovation that employs tactile sensations or vibrations to relay information to users. This integral component is pivotal in user interfaces and technological applications, serving multifarious functions that include augmenting user experience, diminishing cognitive burden, and engendering a realistic depiction of physical sensations.

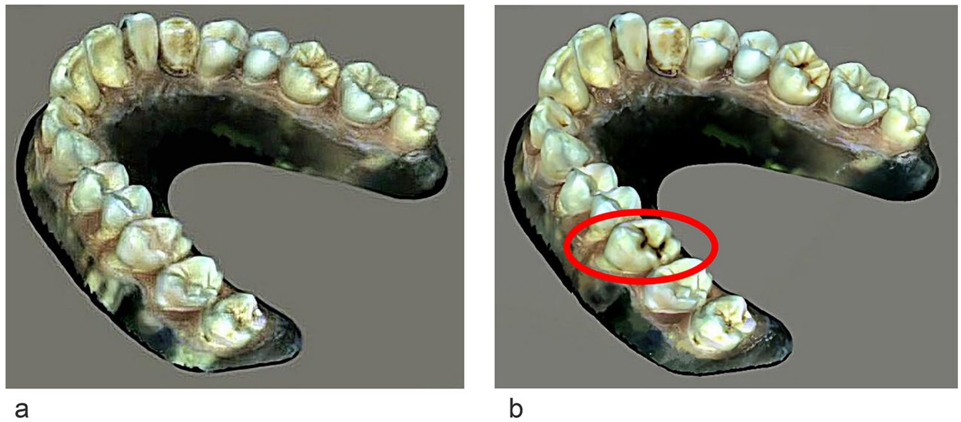

Fig. 1 (**a**) Clinical intra-oral scan of a real patient dentition, (**b**) Caries and staining were simulated on molar teeth to create a life-like case for practicing dental charting

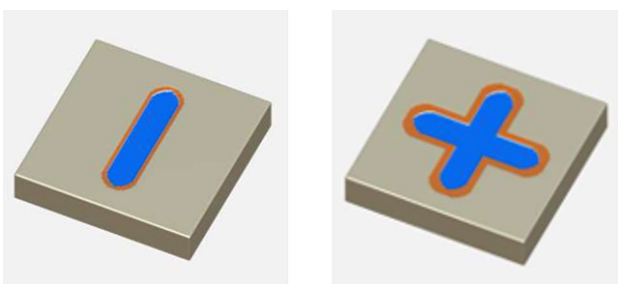

Fig. 2 Virtual block showing manual dexterity exercise, following a stained "channel" and "cross" shape

Additional features including a foot pedal, height adjustment mechanism, and dental chair are incorporated to mimic clinical environments, thereby enhancing the authenticity of the simulated experience. A good quality clinical intra-oral scan (ply file) of a real patient dentition was shared with SIMtoCARE (Fig. 1a) to be imported onto the simulator hardware (drag and drop in the scan interface tool that is available on the iMac teacher station), which generated a QR code that can be read by the simulator. This was then added to the standard library. Caries and staining were added/simulated on the teeth to create a life-like case (Fig. 1b).

In addition to the dental charting task, students performed a manual dexterity exercise on a virtual block, following a stained "channel" and "cross" shape (Fig. 2). The aim of this exercise was to familiarize students with the grasp of the dental handpiece and the feedback sensation from the VRHS.

Once students' progress to year 3, in addition to learning on the VRHS, they learn restorative practical skills utilizing acrylic typodont teeth (Frasasco, ANKA-4 Z, Tettnang, Germany) in manikin-based phantom heads within the simulation laboratory. Before starting this research, third-year students were given multiple training sessions as part of their curriculum, covering different topics. These included examining and diagnosing dental caries, applying rubber dam for moisture control, using dental instruments, understanding the basics of preparing a cavity, and applying fissure sealants. Additionally, all students were shown a detailed, step-by-step demonstration on accessing and removing a carious lesion. This process involved removing most of the decay with a high-speed handpiece and then, where required, eliminating any remaining decay using a low-speed handpiece.

Sampling technique and participants

A homogeneous purposive sampling method was utilized to gather data from third-year undergraduate dental students ($n=23$) at the College of Dental Medicine, Qatar University. Emails were sent to each student, containing a research leaflet that detailed the study's goals and objectives. Joining the study was completely optional, and any data gathered was kept anonymous. Before the study began, each participant provided a signed informed consent form.

For the purpose of this study, all 23 third-year students were split into two groups using an online tool for randomization (https://www.randomizer.org), to sequentially carry out the assigned operative tasks during their scheduled pre-clinical restorative sessions (Fig. 3).

Group 1 (Control group): first practiced Class I cavity preparation using VRHS on a lower right first molar (tooth #36). This was followed by a similar exercise using phantom head and acrylic typodont teeth in a conventional simulated environment (CSE).

Group 2 (Study group): first practiced Class I cavity preparation exercises in a CSE on tooth #36, and then performed the same task using the VRHS system.

By having both a control group and a study group, the research can comprehensively evaluate students' perceptions related to the effectiveness and impact of VRHS in pre-clinical restorative dentistry, leading to evidence-based conclusions and potential advancements in dental

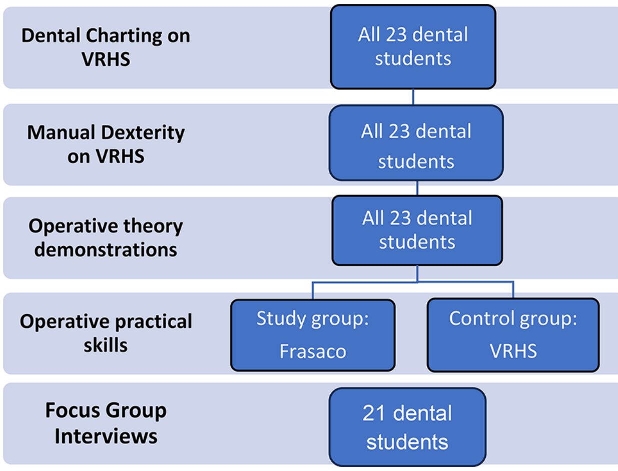

Fig. 3 Student operative tasks allocation during the pre-clinical restorative course

education. Having a control group offers a baseline comparison to help understand the relative advantages or disadvantages of the technology. It can also isolate the effects of VRHS from other variables that might influence students' perceptions and performance. This ensures that any observed differences can be attributed to the VRHS intervention. Moreover, including a control group with a specific sequence enhances the validity and reliability of the study by demonstrating that the outcomes are specifically due to the VRHS and not to other unrelated factors.

For the VRHS cavity preparation exercise, supervisors introduced specific dimensions and depths for the occlusal caries simulations, ensuring the virtual caries' texture—its tactile feedback—was distinctively different from intact enamel and closely mimicked the sensation of removing actual caries. The simulator meticulously recorded each student's duration of activity, the percentage of structure excised, and any deviations from the specified task. This virtual drilling exercise was conducted within a simulated phantom head (Frasaco, P-6/3, Tettnang, Germany) integrated into the VRHS to replicate a patient's head, facilitating the attainment of proper finger positioning during drilling operations. A foot pedal allowed for the adjustment of the handpiece's speed, and a mirror was provided to aid in visualization and ensure proper retraction. Each student was allotted 40 min to complete and submit their task.

The outcomes of these tasks were stored on a central server, with provisions for each student to offer feedback on their experience, thereby fostering a reflective learning environment. Similarly, for the conventional simulated environment, students practiced the cavity preparation within a simulated phantom head (Frasaco, P-6/3, Tettnang, Germany), however, on typodont teeth that is not integrated into a VRHS.

Table 1 Focus group data collection format

Step	Objective
Recruiting	Participants meeting predetermined screening criteria (e.g., demographics, behaviors, experiences) are recruited through multiple channels to ensure their relevance to the research topic.
Logistics	A quiet facility equipped with audio recording capabilities, sufficient space, and appropriate ventilation is chosen. Participants are then brought into a controlled discussion room overseen by a trained moderator.
Discussion Guide	The moderator adheres to a predetermined discussion guide that addresses specific topics and questions, while allowing for a natural flow of dialogue. These guides are meticulously designed to foster an open environment for participants to share their thoughts and opinions.
Group Dynamics	One of the primary strengths of focus groups is the opportunity for diverse participants to share perspectives, generate new insights and build upon each other's opinions. Skilled moderators effectively facilitate these dynamic interactions.
Observation	Moderators must be vigilant to observe firsthand reactions and capture significant non-verbal cues.

Study design

This study employed an explorative qualitative design using focus groups to thoroughly investigate dental students' views on the impact of VRHS on their pre-clinical learning. The aim was to uncover any developing trends among students accustomed to virtual reality. The choice of this data collection method was driven by the desire to gain profound insights into an undergraduate dental program that has a comparatively small group of participants [10].

In the course of developing the curriculum for the undergraduate program at Qatar University's recently established College of Dental Medicine, it is crucial to gather insights and experiences that are relevant to the teaching and learning process. Third-year dental students were considered appropriate participants for this study, as they could offer valuable, relevant, and varied data that directly relates to the research question. The authors of the study took on the role of overseeing the distribution of research invitations.

Data collection

Qualitative data collected from focus groups were planned to follow a basic format illustrated in Table 1. All participants were assured that their data would remain anonymous and be handled confidentially. The authors meticulously planned the in-person focus group sessions, ensuring that the interview environment was appropriate, and the location was accessible to everyone. The seating arrangement, either semicircular or circular, was designed to facilitate easy viewing, listening, and interaction among participants during the discussions [10].

A guide for the focus group discussions was created to ensure that conversations stayed on topic and to standardize data collection. This guide was elicited based on the research question and developed through a literature review and discussions with the research team. It included open-ended, neutral questions to minimize bias. To ensure questions were relevant and understandable, the topic guide was initially piloted on a number of students [10]. Ground rules were established when building the focus group discussion guide, including the use of "Funneling Techniques", whereby the moderator starts broader and funnels down to the specifics to ensure participants are more comfortable sharing openly. Also, avoiding going through the guide rigidly, rather, adjusting the order, skipping and rephrasing, in order to emphasize the interesting areas emerging and delving deep into relevant points.

Some of the key questions in the guide asked students about their perceptions of the simulators' effectiveness in teaching manual skills, whether they found the haptic feedback realistic, how the haptic experience compared to training on natural and "Frasaco" acrylic teeth, the strengths and weaknesses of using haptic simulators, and potential areas for improvement.

Focus group interviews were conducted in English during the Spring semester of 2023, contained a moderator and observer, and lasted approximately 60–90 min each, to ensure comprehensive data collection while avoiding participant fatigue. Effectively moderating a focus group necessitated strategic management and strong interpersonal skills to steer the discussion and maintain its focus. It was crucial to refrain from participating, leading, expressing personal opinions, or correcting participants' knowledge, as these actions may introduce bias. Adopting a relaxed and attentive demeanor can help participants feel at ease and encourage open dialogue. Moderators also ensured that no single individual dominated the conversation, facilitated fair discussion of differing opinions, and encouraged quieter participants to share their thoughts when necessary. Based on the literature, the optimum size of focus group, excluding researchers, is around six to eight participants. During the group discussions, any emerging issues were explored in depth, and participants were prompted to provide more detailed explanations of their responses [11]. Data saturation, referring to the point in qualitative research where no new information or themes are observed in the data, was determined through the following steps:

A) Initial coding of the focus group transcripts, to identify themes, patterns, and categories that emerge from the discussions.
B) Continuous comparison of new data from subsequent focus groups with the existing codes and themes.
C) Memoing insights, and decisions throughout the data collection process to help track when no new themes are emerging, and the data is becoming repetitive.
D) Reviewing the literature to compare emerging themes with existing literature. This helps in validating the themes and confirming that no significant areas have been missed.

Data reliability was confirmed by comparing responses from three parallel focus groups for each course. Trustworthiness of the inferences was ensured through multiple coding, maintaining an audit trail, and conducting member checking, where focus group participants reviewed the themes for accuracy and validity.

Data analysis

The focus group sessions were recorded and transcribed using Microsoft Teams, and the resulting data was cleaned and shared with participants for feedback. This study followed a six-step data analysis process: becoming familiar with the data, coding, identifying themes, reviewing themes, synthesizing and defining themes, and producing a final report [12]. This process included creating a conceptual framework of themes and subthemes. The data was manually analyzed using an inductive, thematic approach [13]. Further abstraction was then performed to elevate and refine the categories [14]. Two authors, AD and MME independently read the transcripts, coded the text relevant to the research based on both its apparent and underlying content, ensuring the trustworthiness of the data analysis [12]. Throughout this process, the findings were consistently referenced back to the original transcripts to accurately reflect the context and perceptions expressed. Both researchers developed preliminary and secondary lists of codes, and upon reaching consensus, the main codes were established. This stage involved identifying common phrases that conveyed similar ideas or meanings. A third author, KA, validated these codes. Once all data were coded, the codes were compared and organized into relevant themes and subthemes. Themes were defined as patterns or meanings in the data that are significant to the research questions [12]. The research team discussed and resolved any differences in the extracted themes. Representative quotes for these themes were selected based on the research team's consensus. The results are presented in accordance with the COREQ criteria [11].

Results

The age of participants ranged from 19 to 22 years old. Year 3 dental students participating ($n=21$) were divided into 3 focus groups and the gender distribution as shown in Table 2.

The analysis revealed five primary themes, each accompanied by its own set of subthemes. The decisions made by the students who participated were shaped by the factors summarized with the term "MASTR", featuring Realism (R) at the peak of the pyramid, being the most frequently mentioned theme by students, as shown in Fig. 4.

Table 2 Gender distribution of focus groups

Gender	Group 1	Group 2	Group 3
Female	5	4	6
Male	2	2	2

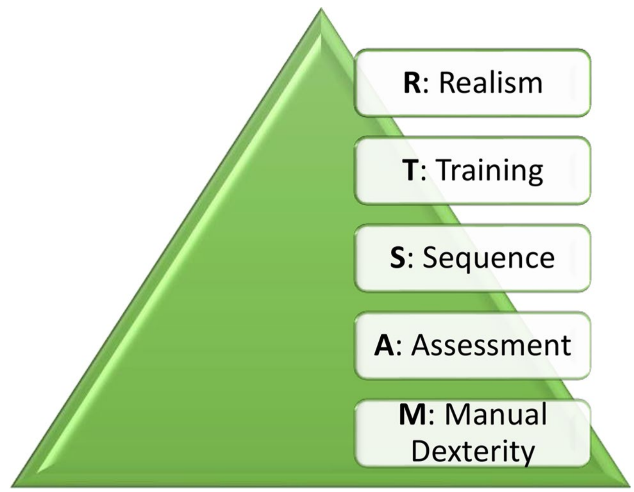

Fig. 4 Five major themes identified from analyzing the qualitative data

Theme 1: manual dexterity

Hand-eye coordination was considered an important aspect of the VR training. Some students felt that training with VRHS helped them control the handpiece.

"*Learning how to control our hand movement and try to be precise*" (Student 4, group 2).

Delving into that, students felt that although the weight and handling of the VRHS handpiece may feel the same as the conventional handpiece, the pressure exerted while drilling in the tooth was different.

"*Drilling on the tooth is different. It is easier to put pressure on the typodont tooth than VR*" (Student 3, group 1).

Another subtheme included reversibility of tasks, identified by students as an advantage of VRHS.

"*I like its reversible, so you can delete the step and go back*" (Student 4, group 1).

"*I felt comfortable that I can do it multiple times*" (Student 1, group 2).

Being able to control the handpiece also emerged as a learning point.

"The most benefit we got initially was learning how to draw lines and circles. I think this helped us control the depth" (Student 2, group 1).

However, one student felt it was challenging to see what they are doing while drilling deep.

"I drill sometimes, and when I remove the bur it looks like a mess. I can't see what I'm drilling" (Student 3, group 1).

Theme 2: assessment

During the undergraduate dental program, pre-clinical training is the steppingstone to clinical practice. Assessing students' competencies prior to clinical practice is paramount for ensuring patient safety. Interestingly, the perception of most students in the current study revealed that they strongly prefer being assessed on typodont teeth rather than VRHS.

"*VR is not really an indicator of how good your manual dexterity is*" (Student 2, group 1).

"*We want to practice and have exactly the same experience as clinics, and haptic devices does not provide that*" (Student 3, group 2).

In terms of limitations of the VRHS in assessing students' progression, students felt uncomfortable relying on the outcome of the task to be used for summative assessments.

"*There are many limitations with VRs, and I don't think it is fair to assess us using haptics*" (Student 4, group 2).

"The device shows me how much diseased tooth structure is remaining in percentage, but I am not sure it would be fair using that to judge a student passing or failing the task" (Student 3, group 1).

"I believe results from working with VRHS could be included in formative assessments but not summative" (Student 4, group 2).

"The assessment functionality in the VR should mimic what is expected on clinic. in other words… replicate the clinical competencies" (Student 3, group 1).

Theme 3: sequence

When designing a curriculum, educators need to be mindful of the skill acquisition sequence, and ideally start with simple training (minimum variability). More than half the participants within this study commented on the sequence of tasks, and felt that VRHS should come first, prior to conventional phantom head training.

"*VR is useful especially at the start, so before starting on the phantom head*" (Student 2, group 2).

"*It's good to practice VR at a very early stage, maybe as early as year 2*" (Student 5, group 1).

"If year 2 get a chance to practice more VR they would get used to the handpiece quicker and then it will be easier for them" (Student 4, group 1).

"I was excited at the beginning... it felt like playing a game, and dentistry was going to be fun, but I soon realised once moving on to typodont teeth that - game over!" (Student 3, group 3).

On the other hand, despite requesting to practice early on VR, the majority of students felt that VRHS training has no added value once they start their training on typodont teeth in phantom heads.

"*It's useful just to give you the feeling, but after that I don't think we need it, like even when I do crown preps it wasn't useful because I've already experienced the handpiece*" (Student 4, group 1).

"*I enjoyed the first session only, only because it was the very first session*" (Student 2, group 1).

"*After trying the drilling into natural teeth, I don't think we need VRHS... I believe we won't need it once we start clinics too*" (Student 3, group 2).

"To me... the freedom of maneuvering around the phantom head, the splashing water and the cheek retraction overweighs the advantages of VR... I would not go back to it now!" (Student 1, group 1).

Theme 4: training

The ability to self-train was raised by dental students as one of the advantages of VRHS. Nearly third of the students perceived practicing on VRHS as a vehicle to obtain instant feedback from the device. As novice trainees, VRHS provided students with a safe environment.

"*It's good for self-training at an early stage*" (Student 4, group 2).

"*Feedback step by step, so we know where exactly when we did something wrong*" (Student 2, group 1).

"*We feel confident doing mistakes without anyone watching*" (Student 3, group 1).

Despite the aforementioned benefits, students felt more content receiving feedback from their supervisors when training, even with the VRHS.

"*I prefer continuous structured feedback from my supervisors than relying on VR*" (Student 5, group 2).

"*It's good for showing us the percentage of how much caries we removed, but structured feedback from faculty will help us improve*" (Student 2, group 2).

"Human interaction with our supervisors is invaluable... the encouragement and positive feedback they provide outlies feedback from the VR device" (Student 2, group 3).

"For consistency, I would like the same supervisor who is marking my final practical exam to provide me feedback throughout the VR experience" (Student 1, group 2).

Theme 5: realism

The lifelike nature (also described as realism) of VRHS is mainly credited to their capacity to mimic the tactile experiences (haptics) that are typical in dental processes, like drilling in tooth structure. Participating students affirmed that one of the most crucial outcomes of pre-clinical training is the ability to replicate real-life scenarios and provide accurate simulation of dental skills. Nearly all of the participating dental students firmly believed that virtual reality haptic simulators fall short of replicating actual experiences. Subthemes emerging from the "realism" theme included feeling/sensation, seating maneuver, dental instruments, depth of vision, finger rest and technical aspects.

"*I think the phantom head is more realistic*" (Student 4, group 2).

"*The sensation... the system sometimes lags and does some weird things like shaking... overall, didn't enjoy it*". (Student 2, group 1).

"*The depth of VR we can't see it, and in the phantom head we can use the probe. VR is supposed to be 3D but not useful in-depth perception*" (Student 5, group 2).

"*We maneuver around the phantom head, but we are stuck with the VR screen... I'd rather practice how to move around the patient's head*" (Student 3, group 2).

"*Not easy to look through the screen... the system also crashed or starts to shake*" (Student 5, group 1).

"It wasn't easy to control the burs. like the bur didn't translate well on the VR. When we moved on and used the typodont teeth, we can see the difference between the round bur and fissure bur, and the smooth burs, and we can feel there is a specific cut for each type of bur. However on VR it was like all just drilling randomly" (Student 4, group 1).

"Although VR is soft and mimics the sensation of natural teeth, it is hard to control compared to the typodont teeth, which I personally prefer" (Student 2, group 3).

Discussion

More recently there has been growing acceptance and adoption of several VR devices into the pre-clinical dental training [15]. Examples of their integration into various dental disciplines include; oral & maxillofacial surgery [16], paediatric dentistry [5] and restorative dentistry [17]. The integration of VR devices within dental training curricula has been driven to overcome limitations of material and methods of traditional pre-clinical teaching [18]. Unfortunately, it is well known that plastic teeth do not simulate the tactile feel of neither sound nor carious teeth. While natural teeth replicate the true clinical scenario, they are limited in supply, lack standardization and could possess a risk of cross infection control [18].

This integration highlights the rapidly evolving nature of dental education, whereby traditional methods are being complemented with cutting-edge technological advancements [15]. Therefore, to further shed light from the user's perspective, this study focused on dental students' opinions of using such sophisticated devices utilizing focus group discussion sessions. Qualitative analysis identified five main emergent themes summarized with the term "MASTR" (M=manual dexterity, A=assessment, S=sequence, T=training, and R=realism). Of interest, a recent scoping review assessing the application of VR in dental training also reported four educational thematic areas; (1) the 'simulation hardware', (2) the 'realism of the simulation', (3) the 'scoring systems' and (4) the 'validation' of the systems [15].

Manual dexterity is well recognized and an important talent and skill for students studying dentistry. This is echoed by a recent study reporting that students choosing to study dentistry exhibit strong inclination towards performing hands-on practical tasks [19]. In this study, dental students reported improvement in their manual dexterity following use of VRHS. Indeed, this theme is in-line with the current dental literature, in which the use of VRHS has shown significant promise in enhancing students' manual dexterity for various dental procedures [18, 20]. These simulators provide a unique platform, especially for the novice students to practice and refine their hand skills in a controlled and non-threatening virtual environment [21]. A study by Urbankova highlighted that VRHS can effectively improve students' manual dexterity, particularly in complex procedures such as cavity preparation, by offering repetitive practice without the risk of harming actual patients [22]. Additionally, a study by Plessas suggested that the integration of VR simulators into dental curricula can lead to improved psychomotor skills, as these tools allow for detailed tracking and assessment of students' performance over time [23].

Secondly, the theme `assessment` was commonly reported by student users. In this study, the VRHS hardware used offered haptic force feedback while the user is performing virtual drilling. The interaction between the stylus (virtual handpiece) and the object (virtual lower first molar tooth; #36) produces visual changes (caries removal) in the 3D image of the #36, that is being displayed on the screen. In-line with the current literature, VRHS have emerged as a pivotal tool for assessing, evaluating, and providing immediate feedback to students during their training, thus enhancing the learning experience [24]. Improved skill acquisition and boosting the confidence of students as they prepare to apply these skills in real-life situations has been documented [1]. Furthermore, analysis of 38 studies from a scoping review highlighted automated simulator feedback as an important aspect and also classified as an educational theme by the authors [15]. Additionally, various assessment approaches were extracted from the literature including; target-based feedback, motion and force exertion tracking, time taken, and clinical feedback [15]. Furthermore, by analyzing student-prepared products using virtual simulators, educational institutions can gauge the proficiency and progress of their students in a more controlled and safer environment [25].

Thirdly the term `sequence` was commonly mentioned. Overall, the majority of participants within this study commented on the sequence of training with an overall agreement to start with VRHS followed by conventional phantom head training. Although some wanted to be familiar with the correct seating position around the phantom head from the start. On the other hand, despite requests to engage in Virtual Reality (VR) training at early stages, some students expressed the viewpoint that the VRHS offered no additional benefit once they commenced their exercises on typodont teeth within phantom heads. In fact, students found that VRHS is a useful device just to give the feeling of drilling, and suggested they provided no supplementary advantage later in the course, particularly for practicing crown preparation for example, as they prefer the flexibility of maneuvering around the phantom head and not being restricted by the VR screen. Moreover, the features of the VRHS handpiece, including its grip, weight, and water spray mechanism, differed from those of a physical handpiece. The aforementioned feedback from students is in line with the literature [17, 26].

The fourth reported theme by the users was `training`. In the context of rapidly evolving dental technologies and practices, self-training in dental education is becoming increasingly important [27, 28]. It involves students taking the initiative to learn and practice skills independently, often using a variety of resources such as online tutorials, simulation models, and peer collaboration. This approach allows dental students to tailor their learning to their individual needs and pace, fostering a more personalized educational experience. In addition, self-training encourages students to develop critical thinking and problem-solving skills, as they are often required to navigate complex scenarios without direct supervision. The long-term benefit of this method of learning is that it cultivates self-reliance and adaptability, two essential traits in the dynamic field of dentistry [29]. Despite the benefits outlined above, students were more satisfied receiving feedback directly from their supervisors during training, rather than relying solely on feedback from the VRHS. Research indicates that concurrent feedback enhances psychomotor skills by elucidating the processes required to achieve the desired outcome, immediately guiding the trainee towards the correct approach, and reducing the cognitive load on memory [30, 31]. Therefore, educators need to be mindful of providing appropriate feedback

Table 3 Recommendations to integrate VRHS into dental curricula

Curriculum Design and Integration	Aligning with Learning Objectives	Identify specific learning objectives and competencies that VRHS can effectively address, such as manual dexterity, spatial awareness, and procedural skills. Integrate VRHS modules into relevant courses, to complement traditional teaching methods.
	Incremental Implementation	Introduce VRHS gradually, starting with specific modules or procedures to allow students and faculty to adapt to the technology. Monitor/evaluate the impact of VRHS on student learning outcomes, adjusting as needed.
	Blended Learning Approach	Combine VRHS with traditional teaching methods to provide a comprehensive learning experience. Use VRHS for complex procedures and simulations while maintaining hands-on practice and theoretical instruction.
Technical and Infrastructural Support	Access and Availability	Ensure that VRHS equipment is readily available to students, either through dedicated simulation labs or portable devices. Provide sufficient units to accommodate all students and avoid scheduling conflicts.
	Technical Training	Offer training sessions for students/ faculty to familiarize them with the VRHS. Provide ongoing technical support and ensure smooth operation.
Enhancing Educational Benefits	Realistic Simulations	Develop high-fidelity simulations closely mimicking real-life scenarios. Continuously update and improve the simulations based on feedback and advancements.
	Feedback and Assessment	Implement systems for immediate feedback during VRHS sessions to help students learn from their mistakes and improve their skills. Use VRHS data to assess student performance and track their progress over time.
	Encouraging Collaboration	Create collaborative VRHS activities where students can work together, share insights, and learn from each other. Incorporate group simulations to enhance teamwork and communication skills.
Addressing Concerns and Challenges	Cost and Resources	Explore funding options, such as grants, partnerships, or industry sponsorships, to offset the cost of VRHS technology. Ensure efficient use of resources by integrating VRHS into multiple courses.
	Resistance to Change	Address any resistance from students or faculty by highlighting the benefits of VRHS and providing evidence of its effectiveness. Involve faculty in the planning and implementation process to ensure their support.
	Ethical Considerations	Ensure VRHS adheres to ethical standards and provide a safe learning environment. Address any concerns about data privacy and the appropriate use of simulation data.

and direction to students during the VRHS training session.

Lastly, the term `realism` was commonly reported by the dental students when performing a standard class I cavity preparation with VRHS. Indeed, with significant advancements, VRHS have become more sophisticated, thus offering a realistic and immersive environment for dental students. The realism of these simulators is primarily attributed to their ability to replicate the tactile sensations (haptics) encountered during dental procedures, such as drilling or scaling. For instance, a study by Al-Saud et al. highlighted the effectiveness of haptic technology in simulating the feel of different tissues and resistance levels experienced in real-life dental procedures [31]. Furthermore, the ability of haptic feedback in these simulators to offer a realistic touch and resistance sensation, closely mimicking the experience of real dental materials and tissues is advantageous [24]. This tactile feedback is also crucial in developing and further refining fine motor skills and hand-eye coordination. However, it is crucial to note that while VR simulators offer a high degree of realism, they cannot fully replace the experience of working on typodont teeth or actual patients, as suggested by studies like Buchanan; the integration of VRHS in dental education serves as a complement to traditional methods, providing a risk-free, controlled environment for initial skill development [7]. Features such as an interactive computer screen and advanced haptic interfaces, allow students to practice dental procedures in a simulated environment that closely resembles the clinical scenarios [32]. To summarize, findings from the current study emphasize the importance of enhancing realism in virtual reality haptic simulators and their integration into the dental curriculum. This leads to improved skill acquisition, including tactile feedback which is crucial for developing fine motor skills and precise hand movements necessary for dental practice [27], and visual realism, involving high-fidelity graphics and lifelike anatomical models that help students better understand the spatial relationships and morphology of dental structures, enhancing their diagnostic and procedural skills. Realism can also enhance the learning experience by creating a lifelike clinical immersive setting to help bridge the gap between theoretical knowledge and practical application [33]. Moreover, introducing realistic simulators early in the dental curriculum allows students to become familiar with clinical procedures and instruments from the beginning of their training. This early exposure can shorten the learning curve when transitioning to real patient care [31].

Despite all of the above extracted educational themes and reported benefits, there is a general consensus in the current literature that while VRHS are a valuable tool for skill development, they should complement, rather than replace, traditional hands-on training on typodont teeth [7]. The authors acknowledge that the data is from a single institution which may limit the value of the findings. Nevertheless, the methodology and data analyses have been reported in a succinct and transparent manner to enhance the transferability of the current research. Qualitative methods were used to gain rich insight into students' perspectives, which would have been difficult to orchestrate in larger cohorts.

Based on findings from the current study, recommendations to integrate VRHS into dental curricula can be summarized as described in Table 3.

Conclusion

Virtual reality haptic simulators play a crucial role in modern dental education, offering innovative solutions for training, evaluation, and feedback. The need to enhance their ability to simulate real-life dental procedures (realism), coupled with interactive and immersive learning experiences were the most frequently raised theme by students. Further advancements in the VRHS software and hardware are required for optimal benefit. In terms of curriculum design and learning pedagogies, dental educators should consider the appropriate sequence when integrating VRHS, faculty training, and triangulation of feedback.

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Data availability
The data that supports the findings of this study are available on request from the corresponding author. The data are not publicly available due to ethical restrictions.

Declarations

Ethics approval and consent to participate
The study protocol and participant consent forms were approved by the Institutional Review Board of Qatar University (Reference number: QU-IRB 1652-EA/22). Informed consent was obtained from all subjects involved in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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