


Virtual reality in the teaching of undergraduates in Dentistry: an integrative review

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Abstract The objective of this study was to investigate, through a literature review, the use of virtual reality in the teaching-learning process of undergraduate Dentistry. This is an integrative literature review study, with high sensitivity searches, carried out in the Medline (PubMed), EMBASE (Elsevier), Cochrane Library and Virtual Health Library databases, using descriptors related to virtual reality, teaching in Dentistry and education, with related terms retrieved from MeSH, DeCS and Emtree. The search was carried out in May 2022 for clinical trials in Portuguese, English or Spanish. After evaluation using the established inclusion and exclusion criteria, 14 clinical trials, published between 2004 and 2021 in English, were included. The most tested purposes of virtual reality technologies were for cavity preparations for caries removal (n=7) and in theoretical teaching (n=2). Regarding participant assessment instruments, the practical assessment of manual dexterity was the most used (n=9). The most recurrent limitations (n=6) were deficiencies in the evaluation or evaluation methods of the studies. Thus, it is concluded that the use of virtual reality in the area of Dentistry has the potential to improve technical skills and complement the teaching of theoretical subjects in undergraduate courses. Considering this potential, it is suggested that more studies be carried out to improve the effectiveness and applicability of virtual reality in undergraduate studies.

Descriptors: Virtual Reality. Education, Dental. Education Technology.

Realidad virtual en la enseñanza de pregrado en odontología: una revisión integradora

Resumen El objetivo de este estudio fue investigar, a través de una revisión de la literatura, el uso de la realidad virtual en el proceso de enseñanza-aprendizaje de la carrera de Odontología. Se trata de un estudio de revisión integradora de la literatura, con búsquedas de alta sensibilidad, realizado en las bases de datos Medline (PubMed), EMBASE (Elsevier), Biblioteca Cochrane y Biblioteca Virtual en Salud, utilizando descriptores relacionados con la realidad virtual, la enseñanza en Odontología y la educación, con temas relacionados. términos recuperados de MeSH, DeCS y Emtree. La búsqueda se realizó en mayo de 2022 de ensayos clínicos en portugués, inglés o español. Tras la evaluación mediante los criterios de inclusión y exclusión establecidos, se incluyeron 14 ensayos clínicos, publicados entre 2004 y 2021 en inglés. Los usos más probados de las tecnologías de realidad virtual fueron la preparación de cavidades para la eliminación de caries (n=7) y la enseñanza teórica (n=2). En cuanto a los instrumentos de evaluación de los participantes, la evaluación práctica de la destreza manual fue la más utilizada (n=9). Las limitaciones más recurrentes (n=6) fueron deficiencias en la evaluación o métodos de evaluación de los estudios. Así, se concluye que el uso de la realidad virtual en el área de Odontología tiene el potencial de mejorar las habilidades técnicas y complementar la enseñanza de materias teóricas en los cursos de pregrado. Considerando este potencial, se sugiere realizar más estudios para mejorar la efectividad y aplicabilidad de la realidad virtual en los estudios de pregrado.

Descriptores: Realidad Virtual. Educación en Odontología. Tecnología Educativa.

Realidade virtual no ensino da graduação em odontologia: uma revisão integrativa

Resumo O objetivo deste estudo foi investigar, por meio de uma revisão de literatura, a utilização da realidade virtual no processo de ensino-aprendizagem da graduação

em Odontologia. Trata-se de um estudo de revisão integrativa da literatura, com buscas de alta sensibilidade, realizado nas bases de dados Medline (PubMed), EMBASE (Elsevier), Cochrane Library e Biblioteca Virtual em Saúde, utilizando-se descritores relacionados à realidade virtual, ensino na Odontologia e educação, com termos correlatos recuperados no MeSH, DeCS e Emtree. A busca foi realizada em maio de 2022 por ensaios clínicos nas línguas portuguesa, inglesa ou espanhola. Após avaliação por meio dos critérios de inclusão e exclusão estabelecidos, 14 ensaios clínicos, publicados entre os anos de 2004 e 2021 em língua inglesa, foram incluídos. As finalidades mais testadas das tecnologias de realidade virtual foram para preparos cavitários para remoção de cárie (n=7) e no ensino teórico (n=2). Quanto aos instrumentos de avaliação dos participantes, a avaliação prática de destreza manual foi a mais usada (n=9). As limitações mais recorrentes (n=6) foram deficiências na avaliação ou nos métodos avaliativos dos estudos. Assim, conclui-se que a utilização da realidade virtual na área da Odontologia apresenta o potencial de aprimorar habilidades técnicas e complementar o ensino de assuntos teóricos de disciplinas da graduação. Considerando esse potencial, sugere-se que mais estudos sejam realizados para uma melhor eficácia e aplicabilidade da realidade virtual na graduação.

Descritores: Realidade Virtual. Educação em Odontologia. Tecnologia Educacional.

INTRODUCTION

The training of health professionals has been discussed over the years by the educational script based on traditional methodologies, which fragment the teaching-learning process. The search for technical efficiency and specific knowledge contributed to the solidification of this "banking" education, in which the teacher assumes himself as a "transmitter of knowledge" and the student as a passive agent, receiver of this knowledge^{1,2}.

Many weaknesses are associated with this educational model, in which the student usually has little interaction and motivation in the classroom for the content taught. When the student only plays a role of listener in the school environment he is subject to low performance in the fixation of knowledge, because this condition of listener favors passivity and often forgetting the subjects taught which hinders learning. In addition, the distance between theory and practice, lack of problematization and proximity to social reality predominate³.

Linked to this, it is known that there is still, on the part of some institutions and teachers, a difficulty in accepting changes in the teaching-learning process. However, with the arrival of the COVID-19 pandemic, teaching-learning methods had to be adapted. Teachers, even those who did not use it, had to adopt technology as a resource to keep the curriculum and classes going. In this perspective, something that has been gaining prominence in teaching is virtual reality, considered one of the most innovative technologies of this century in this area, allowing to associate theory with practice, offering immersive and more realistic learning experiences^{4,5}.

Virtual reality allows the creation of a virtual environment and when applied in the area of health, for example, one can evaluate the most varied anatomical forms, as well as train the accuracy of a surgical procedure and the various forms of diagnosis in the human body⁶. When it comes to training health professionals, virtual reality allows students to simulate the most realistic and risk-free procedures practices, as well as learning certification and competencies for specific techniques⁷. In dentistry, the incorporation of technologies in education allowed the implementation of innovative teaching methods in the teaching-learning process, differing from traditional teaching, which does not use technologies in the students' educational process^{8,9}.

Therefore, observing the limitations of the traditional teaching model, as well as the advantages and benefits of the use of virtual reality in the training process of undergraduate students, this study aims to investigate, through a literature review, the use of virtual reality in the teaching-learning process of undergraduate Dentistry.

METHOD

This is an integrative review of the literature, seeking high sensitivity, following the guiding scientific question: "How is virtual reality being used in the teaching-learning process of undergraduate Dentistry?" The search was conducted in May 2022, in the databases: Medline (PubMed), EMBASE (Elsevier), Cochrane Library and Virtual Health Library.

The inclusion criteria established were scientific articles of the clinical trial type that present primary data written in the Portuguese, English or Spanish languages; and studies conducted with undergraduate students in Dentistry, where virtual reality is being inserted in the learning context. The exclusion criteria were studies describing only methodological data and/or incomplete results or not consistent with the inclusion criteria of this review; and validation studies of some virtual reality device or software without evaluation for educational purposes.

The search in the databases used the main descriptors extracted from MeSH and Emtree: "Virtual Reality", "Virtual Reality Exposure Therapy", "Virtual Reality System", "Augmented Reality", "Dentistry", "School Dentistry", "Schools, Dental", "Health Education, Dental", "Dental Education", "Education, Dental, Graduate", "Teaching", "Education", "Health Education", "Education, Professional", "Education, Graduate" and "Graduate Education"; with their respective versions in Portuguese (DeCS) and synonyms suggested by the controlled vocabularies cited related to the theme of this review. The Boolean operator OR was used to combine the main descriptors with their respective synonyms, and the Boolean operator AND to join each combination of descriptors. For each database a search was performed.

No restriction criteria were used in the databases, as well as any type of search filter, considering that the selection of these tools would substantially reduce the amount of indexed articles. In the Medline and EMBASE databases, a clinical trial recruitment strategy was used, based on the study by Robinson and Dickersin, in (2002)¹⁰.

Initially, we performed the removal of duplicates, and evaluation of titles and themes. From this, the abstracts and full texts were read, and when not compatible with the inclusion and/or exclusion criteria, the articles were eliminated. Finally, eligible studies were included by the detailed reading of the manuscript and approach to the guiding question of this study.

After the selection of articles, an organized summary of its contents was made. The process of data extraction of the articles, which were screened, was carried out independently by three evaluators and was guided by a standard analysis form, used in the evaluation of the studies recruited in all the search strategies mentioned above. With disagreements in the collected data, the inclusion of these in the study was conditioned to the consensus among the trio of reviewers.

RESULTS

The application of virtual reality technologies to improve learning and manual dexterity of students in undergraduate dentistry has been studied in recent years. A total of 164 publications was retrieved from the databases, and after the stages of screening and application of the eligibility criteria, 14 clinical trial articles remained to compose this review (Figure 1).

The articles were published between the years 2004 and 2021 in English, using as research public students of the Dentistry course ranging between the first and last year of graduation. The sample number varied between 20 and 130 students of both sexes (male and female) distributed in at least two groups (control and experimental). The total follow-up time of the studies ranged from one hour and seventeen minutes up to one year of tests.

The virtual reality technologies tested in the studies had mainly the objective of improving the learning and manual dexterity of the students in the accomplishment of dental procedures, as cavitory preparations for removal of caries (n=7), endodontic access (n=1) and porcelain crowns fused with metal (n=1); marking, drilling and widening of holes for dental implants (n=1); intraoral anesthetic technique (n=1); periodontal treatment (n=1); and theoretical knowledge (n=2). The main results found, as well as the technologies tested and their purposes, are described in Table 1.

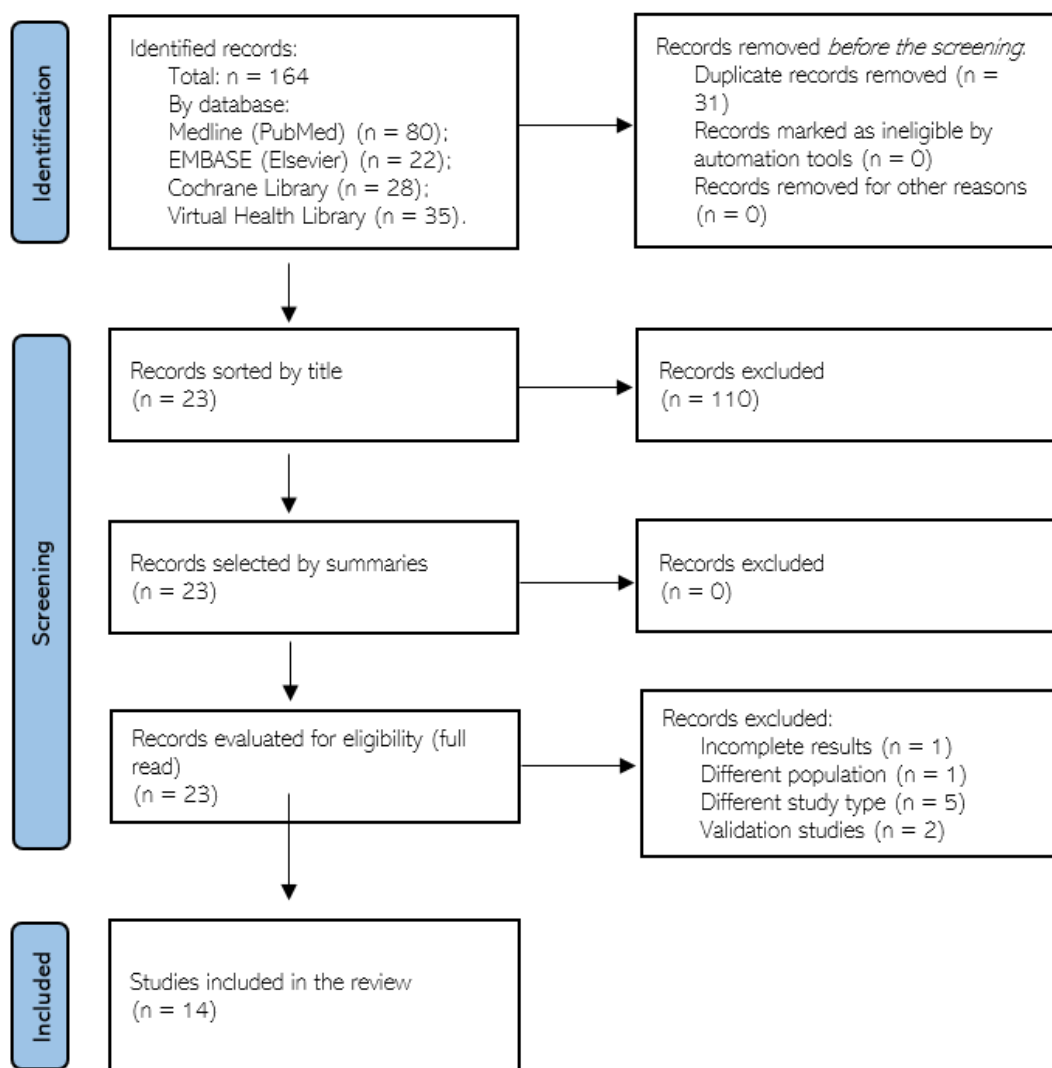


Figure 1. Flow diagram of study selection, following the PRISMA 2020 protocol.

In relation to the assessment tools used in the studies, to measure the effectiveness of the use of virtual reality in the teaching-learning process, it was observed that three different assessment instruments were applied: the questionnaires with answers evaluated by scores of scores obtained by the students (n=3); the performance scale, fostered by responses evaluated by practical performance with pre-established criteria (n=3); and the practical evaluation, used in greater quantity (n=9) based on the analysis of a blind evaluator to qualify students' performance. Only one study used two instruments to analyze the effectiveness of the technology tested, being them the performance scale and the practical evaluation.

The potential of the virtual reality technologies tested, as well as the limitations present in the studies are points that also deserve to be analyzed. Regarding the potentialities, it was observed that most of the technologies stood out for facilitating the practical learning of dental clinical procedures with the tactile sensation similar to reality and interactive visualization of the oral cavity. In addition, from the perspective of theoretical teaching, the development of students' autonomy in the acquisition of knowledge and in the self-assessment of their learning were benefits identified in some technologies (Table 2).

As for the limitations found in the methodological design of the studies, these are mainly related to problems in the pre-training of students (little time in the execution of tasks for a first contact with technologies), evaluation or evaluation methods (absence of evaluations of methodological reliability, comparisons between the analysis by teachers with the

technologies and specifications of the evaluation processes), in the number of individuals recruited (non-representative sample number) understanding of the methodological design (lack of more clarifying information for reproducibility of the study).

Table 1. Methodological data and main results of the included studies.

Publication (Author, year)	Purpose of Virtual Reality Technology	Tested Virtual Reality Technology	Main results
Quinn et al., 2003; ¹¹ LeBlanc et al., 2004; ¹² Wierinck et al., 2005; ¹³ Wierinck et al., 2006; ¹⁴ Dwisaptarini et al., 2018; ¹⁵ Vicent et al., 2020; ¹⁶ Murbay et al., 2020. ¹⁷	Cavity preparation for removal of caries	3D Micro-CTs (SkyScan 1172); Omni Visuo-Tactile Virtual Reality Simulator (SensAble); DentSim® computer-aided simulator (DenXLtd); MoogSimodont dental trainer simulator (Mooq BV); YRBT operational simulator; Virteasy Haptic Simulator; and DentSim™ Browser	For most of the technologies tested there were no significant differences between the experimental and control groups, both had similar performance results
Suebnuakarn et al., 2011. ¹⁸	Cavity preparation for endodontic access	Haptic virtual reality simulator with computed tomography	Post-training performance improved significantly ($p < 0.05$) compared to pre-training performance in the error scores in performing the procedure in the experimental and control groups
Kikuchi et al., 2013. ¹⁹	Cavity preparation for porcelain-fused-to-metal crowns	DentSim Virtual Reality Simulator Download	The total scores of the students of the two experimental groups tested were significantly higher than those of the control group ($p < 0.05$)
Mladenović et al., 2020. ²⁰	Intraoral anesthetic technique	Dental Simulator mobile app	Significant improvement ($p < 0.05$) of the participants of the experimental group in relation to the control group, which also had a better mean of time to perform the procedure
Nardy et al., 2011. ²¹	Marking, drilling and widening of holes for dental implants	Navigation system in virtual reality DenexImageGuidedImplantology (DenXAdvanced Dental Systems)	In the first mandibular hemiarch the experimental group performed significantly better than the control group ($p = 0.016$). In the second hemiarc, the performance of the control group seemed better than that of the experimental group ($p = 0.05$)
Zhang et al., 2021. ²²	Periodontal treatment	UniDental Virtual Reality System	The findings showed no significant difference ($p > 0.05$) in the first theoretical results among the four groups tested. The two experimental groups that performed training in virtual mandible obtained better significant performance ($p < 0.05$) in the second theoretical exam, in the operational and dimensioning process
Hashemikamangar et al., 2016; ²³ Vadillo et al., 2019. ²⁴	Theoretical knowledge	Immersive experience through "SARMAD" e-learning from Tehran University of Medical Sciences Virtual School; and Second Life System (LindenLab)	Significant improvement in the experimental groups by the technologies tested according to the learning objectives analyzed

Table 2. Main strengths of the tested virtual reality technologies and weaknesses/limitations of the included studies.

Publication (Author, year)	Study Locations	Potentialities of Tested Technologies	Weaknesses / Limitations of Studies
Dwisaptarini et al., 2018; ¹⁵ Nardy et al., 2011. ²¹	Thailand and Israel	Interactive visualization of hard oral tissues with color differentiation; and tactile sensation similar to reality in performing clinical procedures	Short time of pre-training
Hashemikamangar et al., 2016; ²³ Kikuchi et al., 2013; ¹⁹ LeBlanc et al., 2004; ¹² Mladenović et al., 2020; ²⁰ Murbay et al., 2020; ¹⁷ Quinn et al., 2003. ¹¹	Iran, Japan, Canada, Kosovo, China and Ireland	Autonomy of students in the acquisition of knowledge and self-assessment; ease in practical learning of procedures; low cost when it allows the use in smartphone; and possibility of several schedules with different contents	Weaknesses in evaluation or evaluation methods
LeBlanc et al., 2004; ¹² Vadillo et al., 2019; ²⁴ Suebnuakarn et al., 2011. ¹⁸	Canada, Peru and Thailand	Ease of practical learning of procedures with reduced margins of error; and realistic simulations of dental care	Limited samples
Vicent et al., 2020; ¹⁶ Wierinck et al., 2005; ¹³ Wierinck et al., 2006; ¹⁴ Zhang et al., 2021. ²²	France, Belgium and China	Ease in practical learning of procedures; interactive visualization of oral hard tissues; and tactile sensation similar to reality in performing clinical procedures	Weaknesses in the methodological design

DISCUSSION

Dental education concentrates much of its workload in clinical care, with the aim of training and practical training of students. Thus, teachers and students need to develop skills and abilities in training to act in comprehensive health care^{25,26}. This is often challenging, since it involves the search and planning of the best teaching strategies to qualify the training of students, and the use of virtual reality in graduation has been gaining more and more space in this process²⁷.

Among the various dental procedures learned at graduation, the restoration of dental elements affected by caries is one of the most performed in the clinic²⁸. Half of the articles included brought applications of virtual reality systems to assist in learning and manual dexterity of students in performing the removal of carious tissue. Two studies found that training with a DentSim™ virtual reality browser (Image Navigation, Moshava, HaZafon, Israel) with feedback from instructors provided better overall performance ($p < 0.05$) manual dexterity, especially in the evaluation of the depth of the pulp wall, with less risk of exposure to pulpar^{13,14}. However, it was observed that the constant feedback condition was not effective in the short term, and this feature can arouse the student's dependence on this condition, interfering in the formation of skills and abilities.

When tested the simulator Moog Simodont dental trainer (Moog BV, Nissin Dental Products, Nieuw-Vennep, Netherlands), 75% of the students of the experimental group ($n=18$) had success in the preparation cavity for restoration Class 1, while only 43% of the control group ($n=14$) were successful. This simulator allows a faster transition of students from the preclinical study to the clinical study, in addition to providing treatment plans for a wide variety of cases of patients and dental pathologies, as well as the possibility of self-assessment¹⁷.

However, although some virtual reality systems show good results in the overall performance of students in cavity preparation, some studies have not found significant differences between the use of technology and conventional practice^{12,15,16}. It was observed in two studies that in retaining the cavity walls the use of technology was as effective as conventional practice^{11,13}. This criterion is of fundamental importance since the success of restoration, especially in large cavities, also depends on the prepared retentive areas²⁹.

Other types of cavitory preparations commonly performed in clinic are those for endodontic and/ or prosthetic purposes, for receiving dental crown. Regarding the preparations for endodontic access, one study demonstrated that the use of a haptic virtual reality simulator with computed tomography generated a significantly better performance ($p < 0.05$) post-training of students in the execution of the procedure¹⁸. As observed in a study that verified the use of a virtual reality simulator DentSim for cavity preparation for porcelain crowns cast with metal, in which the scores obtained by the students in the stipulated evaluation criteria and preparation time were significantly higher ($p < 0.05$) than those of the control group¹⁹.

These results demonstrate the potential of virtual reality technologies in the teaching of cavitory preparations, and it is important to emphasize that teacher monitoring in this process is essential for the evaluation and control of the effectiveness of technologies. Guidance and evaluation by professional teachers are indispensable and virtual systems cannot completely replace traditional training courses³⁰.

Regarding the area of anesthesiology, a study tested the use of a smartphone application Dental Simulator to assist in the practice of blocking the inferior alveolar nerve, where significant improvement was observed ($p < 0.05$) in the learning and manual dexterity of the students of the fourth year of graduation who used the application, as well as in the time of accomplishment of the procedure²⁰. This result corroborates with a study that tested the practice of anesthesia of blockade of the inferior alveolar nerve, of beginners in the area, with a haptic device of virtual reality, in which its use was considered quite satisfactory for the training of anesthesia, considering the needle insertion task, which includes the correct insertion point and depth, as well as the perception of tissue resistances during insertion³¹.

As for more specific procedures, which are often not experienced at graduation, there is rehabilitation with dental implants. In implant dentistry, a survey tested the virtual reality navigation system Denex Image Guided Implantology® (DenX Advanced Dental Systems, MoshavOra, Israel) to perform procedures prior to the installation of dental implants by last year students, in which it was observed that in the first test of the procedures in a mandibular hemiarch, the experimental group had a better performance when compared to the control group ($p = 0.016$). However, the execution of all tasks was significantly faster in the control group than in the experimental group (60.75 vs 77.25 minutes, $p = 0.02$)²¹. This result can be justified by the fact that in the control group the methodology used in the procedures was the conventional, which combined with the repetitions performed by the students; their performance can be optimized when compared to the use of a new system.

Regarding periodontal health, a study evaluated the effectiveness of the UniDental virtual reality system (Zhonghui Technology Institute, Shanghai, China), accompanied by theoretical and practical training on basic periodontal knowledge, performance of students in performing supra gingival scrapings, presenting a better significant performance ($p < 0.05$), for those who composed the experimental group, in the theoretical, operational and dimension evaluations²². The use of theoretical and practical training prior to the tests was an important strategy, since the understanding of factors related to oral tissue health and the technique of procedures are essential for the success of periodontal treatment.

In this perspective, some authors reinforce that the preparation of the student still in graduation is decisive for the quality of care, and should be evaluated from the elaboration and use of strategies that favor the characterization of theoretical knowledge student's practice in the execution of clinical procedures³². Corroborating with this line of thought, two studies evaluated the effects on the learning of dental theoretical subjects from the Second Life²⁴ system and immersive virtual reality in e-learning "SARMAD"²³ (Tehran University of Medical Sciences, Tehran, Iran) students of the fifth and final semester of graduation, respectively. In both studies, there was a significant improvement ($p < 0.05$) in knowledge, in post-tests applied in experimental groups, especially in learning objectives related to understanding concepts and interpretation. Despite the positive results, it is noted that the Second Life system, as a restricted educational approach, does not have the potential to improve students' learning for situations that require personal relationships.

Evaluating the satisfaction of students ($n=32$) with immersive experiences of virtual reality in theoretical teaching, 70% of these stated that they would suggest the e-learning "SARMAD" as an efficient educational modality and 93,3% stated

that this method would be beneficial as a complement to conventional education²³. However, there are also reports of criticisms and restrictions on e-learning, such as the need to simplify the navigation of programs, the presence of more self-assessment³³, and teacher training exercises to use e-learning³⁴, in addition to the understanding that this resource cannot bring a change in teaching alone³⁵. Thus, virtual reality demonstrates potential as a complement to conventional teaching, enriching the teaching-learning process of students, but it is important that an adequate evaluation for virtual reality systems is performed by the studies, effectiveness, applicability and limitations in the educational field.

In this follow-up, analyzing the evaluation instruments used by the studies included in this review, it was observed that the practical evaluation was the most used instrument (n=9). However, the clinical and evaluative look changes according to each individual, generating a greater limitation with regard to the reliability criteria of this instrument, since it is difficult to standardize the way these evaluators outlined their results. As for the applicability of the technologies tested, it was observed that no study was conducted in Brazil, which presents an economic and social scenario different from countries of the Asian and European continent that were where most of the included studies were conducted (n=7 and n=4, respectively). Part of these countries has a higher level of development than Brazil and greater investments in education, which favors the insertion of virtual reality technologies in the university.

Thus, what can justify the lack of studies on this subject in Brazil is the high cost associated with the implementation of these technologies in graduation. Since a potential limitation of virtual reality is the cost of introducing equipment, including softwares³⁶, mainly thinking of a large-scale implementation for a population of university students. Thus, despite the potential observed in the technologies tested, which demonstrate applicability mainly in the development of manual dexterity in students, strategies should be sought to reduce costs and make more accessible for graduation, quality, thus envisioning feasibility of implementation in underdeveloped countries.

As for the limitations found in the studies, which have repercussions on the methodological design, it was observed that the weaknesses in the evaluation or evaluation methods were considered as quite recurrent limitations. This can be explained by the need to briefly describe the entire evaluation process to increase the reliability of the results. The greater delineation of this information will enable a better analysis of the effectiveness of virtual reality systems, so that teachers feel safer and aware of applying them in undergraduate education, thinking mainly in the qualification of the learning of the students of Dentistry and in the preparation for the labor market.

Given the limitations found and weaknesses in the processes of evaluation and elaboration of virtual reality technologies, it is emphasized that, although there are very promising resources, some of the technologies did not perform satisfactory results when compared to the conventional teaching model. Thus, it is proposed that more studies be conducted seeking less subjectivity in the evaluation of virtual reality technologies through the structuring of evaluative parameters of systems and more elucidated methodological designer.

CONCLUSION

Virtual reality has been used as a valuable tool in the teaching-learning process of dental students. Its use in the area of Dentistry has the potential to improve technical skills related mainly to cavity preparations for removal of caries and as a complement in the teaching of theoretical subjects of undergraduate disciplines. These findings demonstrate a viable path, since these technologies are able to complement the traditional teaching method for clinical skills and theoretical knowledge, preceding, with a better preparation of the students, their clinical care, thus becoming promising instruments for graduation.

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