UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

FACULDADE DE ODONTOLOGIA

Programa de Pós-Graduação em Odontologia

Área de Concentração Clínica Odontológica – Materiais Dentários

REALIDADE VIRTUAL IMERSIVA NO ENSINO DE PRÓTESE FIXA PARA ALUNOS DE GRADUAÇÃO EM ODONTOLOGIA

Rodrigo Alves Tubelo

Orientador: Fabrício Mezzomo Collares

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Porto Alegre, 2018.

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LINHA DE PESQUISA: BIOMATERIAIS E TÉCNICAS TERAPÊUTICAS EM ODONTOLOGIA

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Rodrigo Alves Tubelo

Tese apresentada como requisito obrigatório para obtenção do título de Doutor em Odontologia na área de concentração em Clínica Odontológica.

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“Eu treinei 4 anos para correr 9 segundos...”

Usain Bolt

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RESUMO

O objetivo do presente estudo foi desenvolver um simulador em Realidade Virtual Imersiva (RVI) sobre o preparo de prótese fixa e avaliar a experiência do usuário. Ainda, realizar uma prova de conceito sobre a influência do simulador no conhecimento teórico e habilidade prática de alunos de graduação em Odontologia. O desenvolvimento do simulador passou pelas etapas de planejamento do conteúdo, seleção do dispositivo e desenvolvimento do software. Quatorze alunos de graduação em Odontologia realizaram a experiência. O tempo de realização da tarefa e o número de interações entre o auxiliar e o aluno foram registrados. Após o experimento, responderam a um questionário com dezessete perguntas em uma escala *Likert* avaliando sua experiência. Para avaliação do conhecimento teórico e habilidade prática foram formados dois grupos: o G_{VIDEO} (n = 6) assistiu a um vídeo em 3D através de um computador e o G_{IVR} (n = 7) realizou o experimento com o Oculus Samsung Gear VR. O pré e pós-teste de conhecimento teórico foram aplicados para avaliar o conhecimento. Para a habilidade prática, os alunos realizaram um preparo de prótese fixa dentária em dente de manequim. O tempo de preparo, a massa, o volume e o ângulo do término do preparo foram medidos. Não há correlação entre o número de interações do aluno com o auxiliar e o tempo de conclusão da experiência (r = 0,38, p = 0,20). Não houve diferença no conhecimento teórico e habilidade prática entre os alunos de graduação quando expostos ao simulador em comparação com o grupo que visualizou um vídeo em 3D. Os feedbacks dos estudantes de Odontologia variam entre 4-5 itens no questionário, indicando uma avaliação positiva do simulador. Em relação à motivação para estudar, os alunos acreditam que a RVI pode aumentar seu engajamento no aprendizado. Não há diferença no ganho de aprendizado teórico e habilidade prática quando comparamos o uso da RVI e um vídeo em 3D.

ABSTRACT

The aim of the present study was to develop an immersive virtual reality simulator (IVR) on the preparation of a fixed prosthesis and to evaluate the user experience. Also, realize a proof-of-concept that an IVR simulator of fixed dental prosthesis could enhance learning process of undergraduate dental students. The Simulator was developed and has gone through the steps of content planning, device selection, and software development. Fourteen undergraduate dental students performed the experiment. The time to accomplish the task and the number of interactions between the auxiliary and the student were recorded. After the experiment, they answered a questionnaire with 17 questions on a Likert scale evaluating their experience. To evaluate the theoretical knowledge and practical skill, two groups were formed: G_{VIDEO} (n = 6) watched a 3D video through a notebook and the G_{IVR} (n = 7) undertook the experiment with the Oculus Samsung Gear VR. A pre- and post-test of theoretical knowledge were applied to evaluate knowledge. For the practical ability, the students performed a fixed dental prosthesis in mannequin tooth. The preparation time, the mass, the volume and the angle of the end of the preparation were measured. There is no correlation between the number of interactions between student and auxiliary and the time to finish the experiment ($r = 0.38$, $p = 0.20$). There was no difference in theoretical knowledge and practical ability among undergraduate students when exposed to the simulator compared to the group that used 3D video. The feedbacks of dentistry students vary between 4-5 items in the questionnaire, indicating a positive evaluation of the simulator. Regarding the motivation to study, students believe that IVR could increase their engagement to learn. There is no difference in the achievements of theoretical learning and practical skill when we compare the use of IVR and a 3D video.

SUMÁRIO

1 INTRODUÇÃO

Mesmo com as mudanças pedagógicas e tecnológicas, o ensino ainda é realizado baseado em uma metodologia conservadora de relação professor-aluno delimitada (Gallagher, 2004). Contudo, há um movimento pelo uso de metodologias ativas de ensino, sempre visando a qualidade da formação dos profissionais da saúde (Carnegie, 2012). Para isso, o recurso tecnológico amplamente utilizado, sobretudo no ensino mediado por tecnologia, é o objeto virtual de aprendizagem (OVA).

Esses objetos consistem no uso de tecnologias de informação e comunicação voltadas ao ensino, proporcionando interação entre usuário e máquina. O uso desses objetos mostra resultados positivos no ensino em Odontologia (Tubelo, 2016). O avanço dessas tecnologias permitiu a inserção da Realidade Virtual para auxiliar alunos da área da saúde em seus processos de aprendizagem (Harrington, 2018).

No início do século a simulação de procedimentos odontológicos baseado em realidade virtual já era considerado um recurso tecnológico emergente para o ensino da Odontologia (Buchanan, 2004). A utilização dessa tecnologia estava condicionada à utilização de grandes máquinas e monitores que ocupavam praticamente a área de, aproximadamente, um consultório Odontológico. A inovação tecnológica trouxe a otimização de hardware e software, possibilitando a portabilidade aos equipamentos que utilizavam a realidade virtual.

O termo realidade virtual está associado à interação do ser humano com a máquina através de tecnologia de informação e comunicação, onde coloca o ser humano em outro mundo ou dimensão (Tori *et al.*, 2006). Contudo, a realidade virtual que necessitava de grande máquinas, não necessariamente transportava as pessoas ficticiamente para outros locais, pois normalmente a realidade virtual estava associada a uma tela em frente ao usuário, essa sendo considerada uma Realidade Virtual Não-imersiva (RVNI) (Tori *et al.*, 2006).

Um dos primeiros relatos sobre RVNI encontrados na literatura, voltados ao ensino em Odontologia, foi descrito em 2003 comparando a simulação de preparos cavitários para restaurações de amálgama com o ensino tradicional (Quinn *et al.*, 2003). Os resultados apresentados não mostraram diferença quando comparados de forma isolada, mas a associação de métodos promoveu a melhora de habilidades práticas em alunos de graduação. Em 2013, foi relatada a avaliação da influência de simuladores comparando a interação dos alunos utilizando óculos 3D de imagem estereoscópica nos simuladores de RVNI. O uso do 3D com interação mostrou resultados superior comparados ao grupo sem óculos (Qi *et al.*, 2013). Em 2016, desenvolvemos e avaliamos um simulador da manipulação do cimento de fosfato de zinco em ambiente 2D, mas com elevado grau de interação, imersão e satisfação do usuário, mostrando resultados positivos tanto no conhecimento teórico, quanto na habilidade prática de alunos de graduação (Tubelo *et al.*, 2016).

Atualmente, o termo realidade virtual é associado a diferentes experiências de interação entre usuário e meio virtual, mesmo quando não há o completo transporte e interação do usuário com esse meio. A Realidade Virtual Imersiva (RVI) deve primar pela completa inserção do usuário e, através da utilização de dispositivos que permitam a captura de seus movimentos e reações, criar um feedback multisensorial visando intensificar a sensação de presença neste meio fictício (Tori *et al.*, 2006). As ferramentas mais utilizadas para criar esta imersão são o uso de óculos e fones integrados (headsets), onde o usuário é transportado para outra dimensão através dos sentidos de audição e visão.

Mesmo não sendo uma tecnologia recente, a avaliação da influência da RVI na aprendizagem de estudantes da área da saúde só começou a ter registros na literatura em 2017(Harrington *et al.*, 2018), com a simulação de atendimento de Unidade de Tratamento Intensivo para alunos de pós-graduação em Medicina. Na Odontologia, em 2018 surgiram experimentos voltados a procedimentos cirúrgicos com simulação em fraturas LeFort I (Pulijala *et al.*, 2018a; b), mostrando elevado grau de satisfação dos alunos com o uso do simulador. Como a avaliação da influência desse recurso tecnológico no ensino ainda é incipiente, a plausibilidade no desenvolvimento desses objetos educacionais foi trazida dos experimentos realizados em Realidade Virtual não-Imersiva (RVNI).

A avaliação de recursos educacionais virtuais é um processo complexo quando abrange suas qualidades e pertinências. As pesquisas que oferecem critérios para avaliar a influência da RVI (Pulijala *et al.*, 2018b) e a qualidade dos Objetos de Aprendizagem (Pulijala *et al.*, 2018a) que utilizam esse recurso tecnológico ainda são escassas. Dessa forma, ainda se faz necessária a prova do conceito referente a influência do uso da RVI tanto na experiência do usuário, quanto no seu aprendizado para posterior utilização em larga escala e se torna fator importante para a consolidação dessa tecnologia no uso das TICs voltadas ao ensino da Odontologia.

2 OBJETIVOS

OBJETIVO GERAL

O objetivo do presente estudo foi desenvolver um objeto de aprendizagem em RVI sobre o preparo de prótese fixa em alunos de graduação em Odontologia e realizar a prova do conceito quanto à influência da RVI na aprendizagem dos alunos.

OBJETIVOS ESPECÍFICOS

- Descrever o desenvolvimento de um simulador em RVI voltado ao ensino do preparo de prótese fixa;
- Avaliar a experiência e engajamento do usuário em relação à sua prática no simulador em RVI.
- Avaliar a influência da RVI no conhecimento teórico e habilidade prática sobre o preparo de prótese fixa;

3 MANUSCRITOS

O corpo da presente tese é composto por dois manuscritos:

3.1 MANUSCRITO I: Immersive virtual reality stimulating Dentistry Education: Development and user experience of a VR Dental Training. Submetido ao periódico Journal of Dental Education, em 2018.

3.2 MANUSCRITO II: Immersive rirtual reality in dental fixed prosthesis: A proof-of-concept approach for learning. Submetido ao periódico Journal of Dental Education, em 2018.

Os manuscritos, formatados de acordo com os requisitos dos periódicos aos quais foram submetidos, encontram-se a seguir.

MANUSCRITO I

Immersive virtual reality stimulating Dentistry Education: Development and user experience of a VR Dental Training

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ABSTRACT

Purpose/Objectives: This study aims to describe the development of an immersive virtual reality (IVR) simulator for teaching students the preparation of fixed dental prosthesis, and to evaluate the user experience. Methods: The simulator was developed in three stages: content planning, device selection, and IVR simulator development. The evaluation of the user experience was performed with second-year undergraduate dental students. After they performed the IVR simulator experience, the time to accomplish each task and the number of interactions between the auxiliary and student were recorded. After the experiment, the students answered a questionnaire (17 questions, Likert scale). Results: Using the Samsung Gear VR platform, an IVR simulator was developed for the preparation of a fixed prosthesis in a vital tooth. The average time required to finish the IVR tasks was higher for women (19.98 ± 6.67 min) than for men (14.51 ± 5.09 min). There is no correlation between the number of interactions between student and auxiliary and the time to finish the experiment ($r = 0.38$, $p = 0.20$). Conclusion: The feedbacks of the dentistry students range between four and five items in the questionnaire, indicating a positive evaluation of the IVR simulator. In regard to the motivation to study, the students believe that IVR could increase their engagement to learn.

Keywords: Dental education, Virtual reality, Fixed dental prosthesis, User experience.

INTRODUCTION

The technological innovations of hardware and software allowed the evolution of dental procedure simulators, thereby increasing the likelihood of their use in clinical practice[1]. The effectiveness of information and communication technologies in dentistry teaching have been evaluated since the beginning of the last century[2]. Among various resources available, virtual reality (VR) is shown to be a promising technology in the health teaching market[3].

VR can be conceptualized as a technology that allows the user to explore and manipulate real-time computer-generated 2D or 3D sensory environments[4]. In dentistry, VR has been used mainly by simulators that exploit tactile ability. This feature has shown positive results in the acquisition of skill in dental procedures by the manual dexterity acquired during use of this technology[5, 6].

Currently, VR-based dental procedure simulators are composed of haptic equipment (2018 MOOG INC), in which there is a tactile device to choose the different dental equipment to be used in each hand. Simultaneously, the users can see the execution of the procedure through a 2D or 3D screen. This type of procedure is called non-immersive VR, since the user is partially immersed in the simulated environment[7]. However, with the technological advances and the insertion of VR goggles, the user can be completely immersed in the environment. This type of experience, named immersive virtual reality (IVR), has been barely explored in dentistry.

A topic still unexplored in immersive virtual reality is the user's experience on spatial ability correlated to sex. A systematic review with meta-analysis concluded that men have greater easiness on activities that require spatial skills compared to women[8]. Furthermore, a recent study that evaluated the spatial ability and the comparison between the sexes showed positive results for men[9]. However, no studies evaluating this difference in dentistry students were found.

IVR has been a valuable resource for health teaching[3, 10]. Recently, a medical emergency simulator set in an intensive care unit had shown that medical students who used the IVR felt more confident in taking care of patients in an emergency after using IVR simulator. In dentistry, very few studies have addressed the use of IVR for dental students: one about the development and validation of content[11], and another on the influence of learning assessment[12]. There is also a simulator for bucco-maxillofacial surgery and a simulator of Le Fort I procedure performed through Oculus Rift[11]. The lack of studies evaluating IVR simulators creates apprehension about the effectiveness of this approach for dentistry teaching.

The application of IVR for teaching in dentistry aims to simulate procedures that are difficult to perform in clinical practice[13, 14], for example, the preparation of a fixed dental prosthesis, where high practical skill is required to achieve a successful treatment[15, 16]. Thus, the use of IVR has been proposed for teaching fixed dental prosthesis preparation, and to increase the confidence of students to perform this procedure in clinical practice. Even with the high potential of IVR use in health education, there are reports of its unacceptability by some users, who claim discomfort after using the VR headset[17]. Therefore, the assessment of the user experience concerning the acceptability of the educational resource is as important as the assessment of learning through the simulator. In this sense, the aim of the present study is to describe the development of an IVR simulator for teaching students the preparation of fixed dental prosthesis and to evaluate the user experience.

METHODS

Simulator development

The simulator was developed in three stages: content planning, device selection, and IVR simulator development. The evaluation of the user experience was performed with second-year dental students. The project was approved by the Ethics and Research Committee of the Universidade Federal do Rio Grande do Sul. **Figure 1** shows the flowchart of the study design.

Content Planning

The content of the learning object in IVR was designed to provide the experience of preparing a fixed three-element prosthesis on a vital tooth to the user. The right first lower molar was chosen as one of the pillars of the prosthesis. The main teaching objectives of the simulator were to realize the stages of preparation for a fixed dental prosthesis and to enable the experience in performing it. Considering the interactivity of the IVR, the theoretical knowledge about fixed dental prosthesis was displayed with instant feedback as a pedagogical strategy of the simulation. The content was developed based on a reference book[18]. The pedagogical approach was relational[19], considering that the content was based on the experience of the user as a dental surgeon responsible for performing the procedure of preparing a fixed denture in a vital tooth in a fictitious patient.

Device selection

A survey was developed to test the requirements and functionalities of existing IVR technologies. Features like playback platform, headphones support, level resolution per eye, adjustment of the distance between eyes, focal adjustment, wireless support, tracking position, external trackers, portability potential, control for manual movement, and price, were analyzed to identify the technology that would allow a user-friendly experience without the need of an expensive investment. The search for this information was carried out in the official websites of representatives of each brand or manual of technical specifications, executed in September 2017.

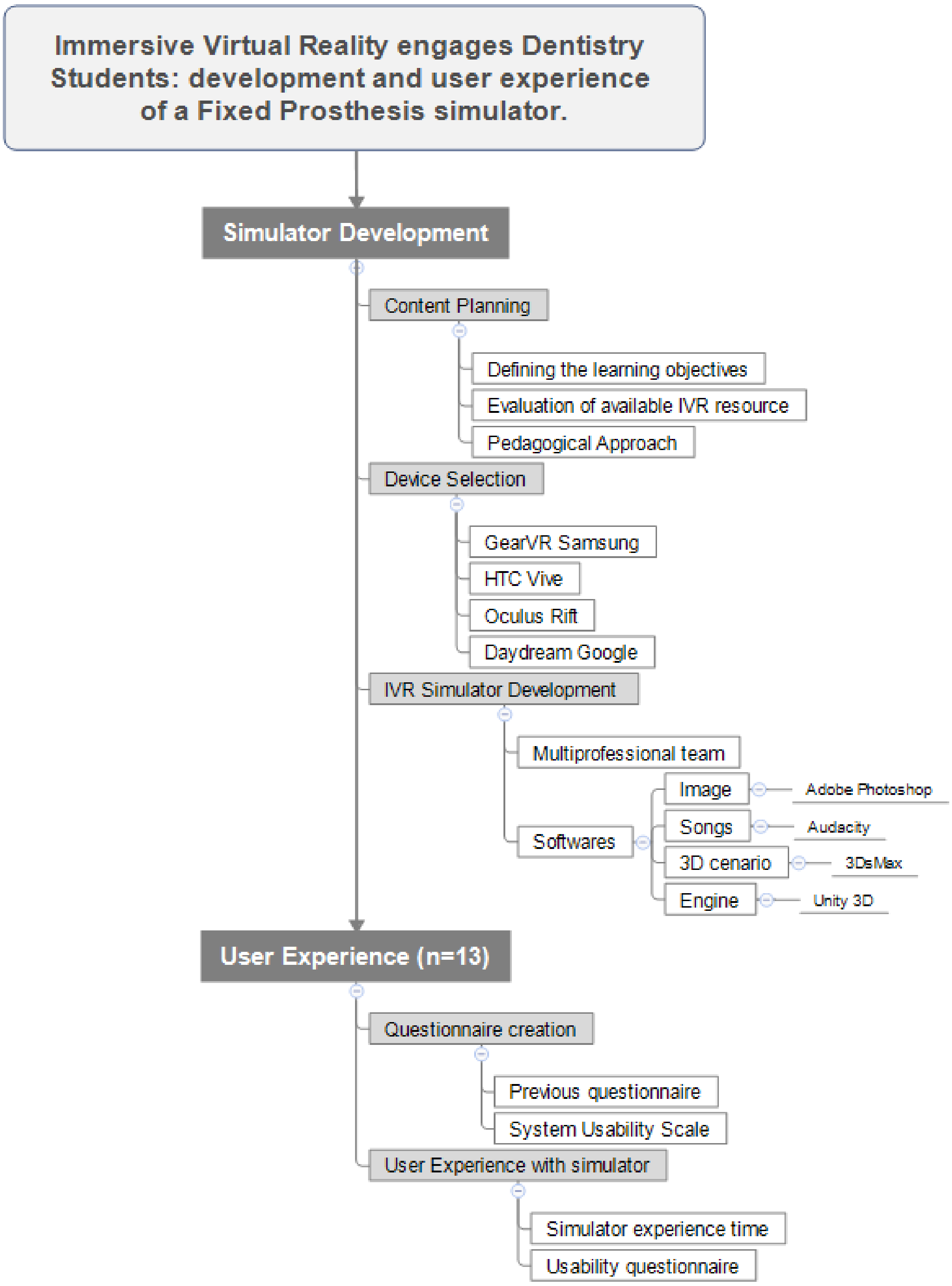

Figure 1. Flowchart with the stages of the simulator development and evaluation of the user experience.

Table 1 shows the characteristics of each of the most used VR headsets on the market. We choose the platform that offered the best portability associated with the gain of processing and visualization potentialities.

Table 1. Main Characteristics of IVR objects (2017).

ITEM/FUNCTIONALITY	HTC VIVE STEAM VR	OCULUS RIFT FACEBOOK	GEAR VR SAMSUNG	DAYDREAM GOOGLE
Platform	PC + Hardware	PC + Hardware	Android/Samsung	Android/iOS
Youtube 360º support	O	O	O	O
Interactive virtual environment	O	O	O	O
Open Hardware	O	O	X	O
Built-in headphone	X	O	X	X
Pixel resolution per eye	1200x1080	1200x1080	1440x1280	Variable
Field of vision	110º	~110º	96º	Variable
Eyes distance adjustment	O	X	X	X
Focus adjustment	O	O	O	X
PC need	O	O	X	X
Position tracking	O	O	O	O
External trackers	O	O	O	X
Portability	X	X	O	O
Movements control	O	O	O	O
Joystick support	O	O	O	O
Initial price (dollar)	$799	$399	$99	$79

O Item contained/supported by platform.
X Item not contained/not supported by platform.

IVR Simulator Development

The development of the IVR resource required the selection of a multi-professional team composed by a dental surgeon for content creation, game developer to perform interactions within the simulator; 3D (third dimension) animator to create the technical dental objects and modeling of the dental arch; and level designer for setting up scenery, lighting, and sound.

The softwares used for development were Engine Unity 3D (Unity Technologies, San Francisco, CA, USA), operated as a simulator engine, due to its capability to compile the simulator that would be used in the Samsung Gear VR (Samsung Electronics Co, Seoul, South Korea) platform; Audacity (Dominic Mazzoni, Pittsburgh, PA, USA) software was applied to edit audios; Adobe Photoshop (Adobe Systems, San Jose, California, USA) was used to create background textures and background images; and 3Ds Max (Autodesk, San Rafael, California, USA) was used for scenario and 3D objects creation.

User Experience Assessment

Thirteen undergraduate dentistry students (second-year) were selected by convenience sampling to participate in the IVR experiment. The user received a Samsung VR Gear headset, a Samsung joystick, and an earphone. Students were divided into two groups according to sex. Interactions between researchers and students were allowed to answer questions about the usability of the IVR object. The time to accomplish each task and the number of interactions between researchers and students were registered. After the experiment, a 17-question questionnaire using a Likert scale (1 - Strongly disagree, 2 - Disagree, 3 - Neither, 4 - Agree, 5 - Strongly agree) was applied to assess the usability of the IVR Simulator from the students' perspective. The questions are shown in **Table 2** and were created based on previous questionnaires used by the same research group[20], as well as the System Usability Scale[21] widely used for evaluations of systems usability developed by the industry.

Statistical analysis

The t-test was applied to the analysis of the time needed to finish the simulation between men and women. Spearman correlation was used to evaluate the correlation among time using the IVR and the number of interactions. To estimate the reliability of the survey, Cronbach's alpha was applied. P-values less than 0.05 were considered statistically significant.

Table 2. Questionnaire evaluating the user experience after practicing in the IVR simulator.

Question:	
A	Had the content of Fixed dental prosthesis Preparation showed on the simulator already been received on another time of your graduation?
B	Are the instructions on the simulator understandable?
C	Has the simulator easy and intuitive navigation, allowing you to easily locate the buttons to execute the commands and evolve in the game?
D	Is the amount of text (content) displayed on each simulator screen adequate
E	Were you able to clearly identify in which step the simulator was every moment
F	Did the rhythm of the simulator make it easier to fix the contents to respond to the evaluation?
G	Did the messages emitted by the simulator use an appropriate language for you?
H	Did the content of the simulator's feedback guide your study on the subject?
I	Did the submitted content allow you to respond to the proposed assessment on the topic?
J	Does the use of the simulator stimulate the learning of new concepts?
K	Does the content presented by the simulator mention real-life situations, making learning more meaningful?
L	Do you feel more confident in preparing a tooth for a Fixed dental prosthesis after using the simulator?
M	Did you have fun while doing the simulation?
N	Have you felt more motivated to learn using the simulator than when you use other traditional methods, such as texts and lectures?
O	Do you believe that using the simulator can motivate learning?
P	Would you like to have access to other learning materials like Dental Training during your graduation?
Q	Do you have a habit of playing electronic games as a form of fun?

RESULTS

Simulator development

The IVR Simulator was developed on the preparation of fixed dental prosthesis in a vital tooth. After evaluating the requirements, Samsung Gear VR platform was chosen, based on the criteria of portability, no need of a PC, field of vision and position tracking through the control. The tasks developed in the simulator were tutorial, presentation of the simulator and virtual scenario, contextualizing the clinical case, selection of diamond burs, textual and vocal guidance of the dental surgeon and execution of the procedure. **Figure 2** shows each of these steps. The relational pedagogical approach aimed to provide experience to perform the procedure independently of the user, guided by the oral instructions and small sentences reproduced by the virtual tutor.

User Experience Assessment

Thirteen students used the IVR and answered the questionnaire. Of these, seven were male and six were female, with a mean age of 20.35 ± 4.38 years for men and 19.66 ± 1.03 years for women, as depicted in **Table 3.**

	n	Age (Mean ± SD)	Previous use of IVR	
Men	7	20.35 ± 4.38	Yes No	3 4
Women	6	19.66 ± 1.03	Yes No	2 4
Total	**13**	**20.53 ± 3.28**	**Yes** **No**	**5** **8**

Table 3. Profile of the sample with mean age and previous experience with IVR.

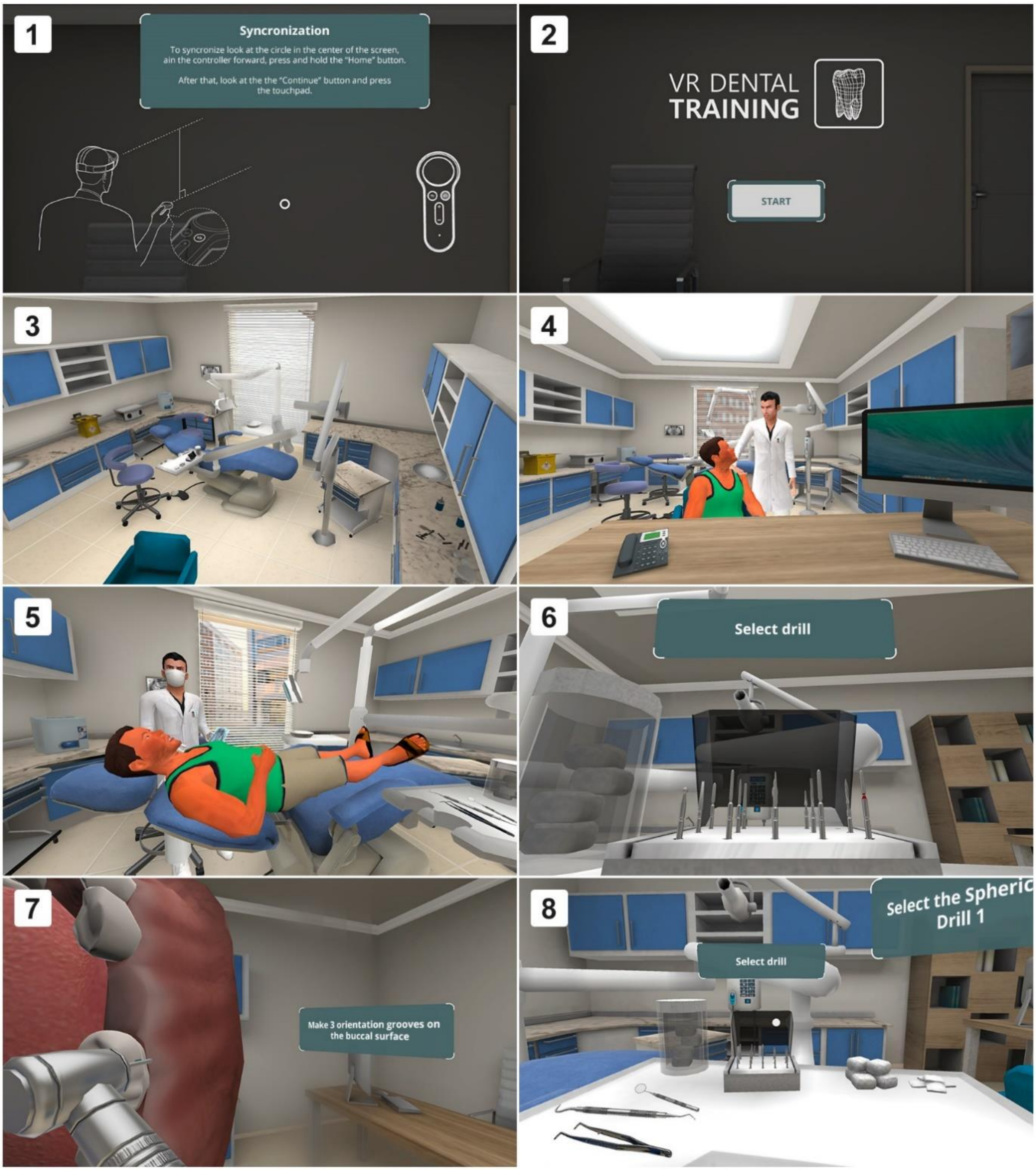

Figure 2. 1 - Instruction for the user to calibrate the control. **2** - Simulator presentation screen. **3** - Environment where the simulator was inserted. **4** - Introduction of the patient by a tutor dentist on the simulator. **5** - Contextualizing the clinical case. **6** - Selection of the diamond tip for preparation. **7** - Guidance and accomplishment of the task. **8** - Changing the diamond tip to start the next task.

The comparison of the time in minutes required to complete the IVR tasks between men (14.51 ± 5.09) and women (19.98 ± 6.67) was not significant ($p = 0.061$), as shown in **Table 4**. Also, the number of student-researcher interactions was not correlated with the conclusion time of the IVR experience ($r = 0.38$, $p = 0.20$).

Table 4. Mean and standard deviation of time with the use of IVR accordingly participants gender.

Group	N	Time of IVR use (minutes)
Men	7	14.51 ± 5.09 A
Women	6	19.98 ± 6.67 A
	p-value	0.061

The results of the user experience assessment are presented in **Figure 3**. Question A ("Had the content of Fixed dental prosthesis Preparation showed on the simulator already been received on another time of your graduation?") is the only item presenting a majority of the strongly disagree answers. The scores 4 and/or 5 of the Likert scale prevailed on the other questions, showing a positive evaluation regarding the usability of the IVR Simulator. The questions N, O, and P demonstrate the high acceptability of students on the use of IVR in dental education. The Cronbach's alpha value was 0.48, which is considered reasonable[22].

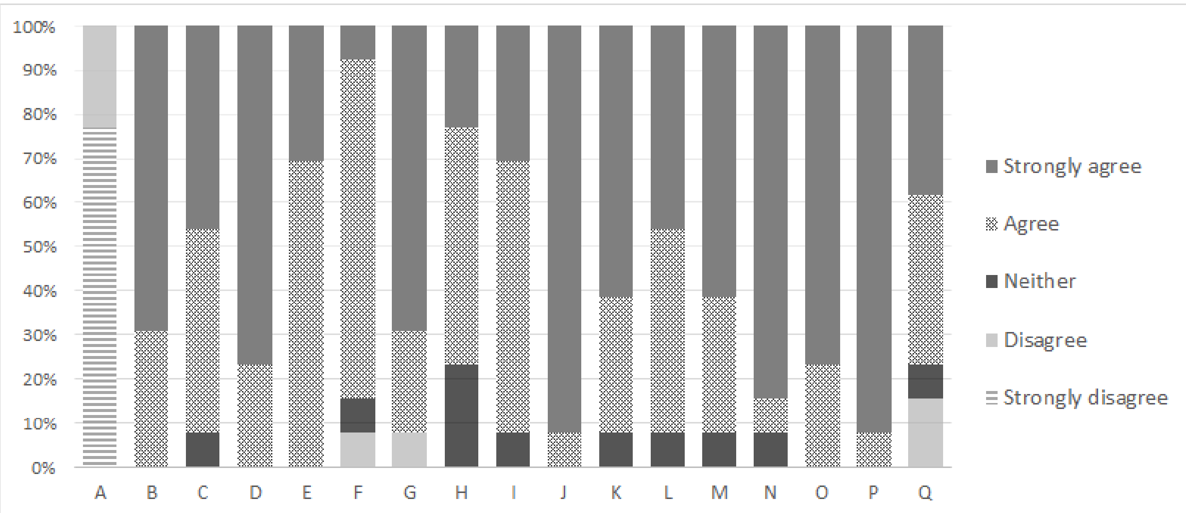

Figure 3. Distribution graph of user assessment on the usability of the IVR simulator, by question.

DISCUSSION

Other studies have evaluated the user experience on learning objects in IVR for health teaching[3, 11]. However, this is the first IVR simulator developed for teaching the preparation of a fixed dental prosthesis. This IVR simulator was evaluated by 13 dental students and obtained positive results in their opinion about the user experience. Also, there was no difference between the time needed to finish the experience between men and women.

In this study, there was no significant difference between the sexes regarding the time needed to complete the experience ($p = 0.061$). This finding corroborates another study that evaluated the difference between the sexes on the learning route, where the sex did not significantly influence performance[23]. Although other studies reported that women have a lower spatial ability than men[8, 9].

Regarding the user experience, 87% of users' responses were between scores 4 or 5 (agree and strongly agree, respectively), positively evaluating the experience. Only 5% of the responses were neutral, and 8% of the scores attributed were categories 1 or 2 (strongly disagree and disagree, respectively). Question A received a score of 1. Therefore, this score was related to students’ lack of knowledge about fixed dental prosthesis theme, so this result was expected. The acceptability of the user to the IVR object is directly related to the persuasive orientation model. Moreover, the learning is enhanced with this orientation modality[24]. This finding complies with the model developed in VR dental training, where the orientation was carried out with affirmative and non-persuasive phrases. The positive result might have been due to the context of each statement, related to each step in the preparation of the fixed dental prosthesis.

The N, O, and P questions shown in **Figure 3** demonstrate that most students prefer to learn through IVR other than traditional teaching methods (84.61%). Furthermore, the students believe the simulator can motivate their learning (76.92%), and they would like to access other IVR materials during their undergraduate studies (92.30%). The results corroborate a study that evaluated the engagement of adults in practicing exercise, in which the group that used VR showed more attention and engagement during the activities[25]. In health education, a VR environment can enhance teaching in multiple perspectives, situated learning, and transfer[26].

All users exposed to the learning object were able to complete the experiment without any discomfort. Usually, there are losses in the sample when we use this approach due to simulator sickness[17]. One of the strategies adopted for success in the IVR simulator was to apply it with adequate ambient temperature (approximately 20ºC) and be careful not to expose users who had insomnia, which is directly related to simulator sickness[27]. Another strategy might be associated with the user experience offered by a device selected, the Samsung Gear VR Oculus, with high quality and fidelity of the visual resources, which are also associated with the engagement and usability[28].

Therefore, the expectation is that retention could be improved with VR Dental Training adding to the pleasant experience provided by the display quality of the virtual object[28], to the approach of active learning for the users granted by the pedagogical concepts used. A comparison between the use of IVR and 2D video goggles showed that IVR had aroused greater attention and engagement of medical students when they were passively exposed in the virtual environment[29]. However, as the remote control for manipulation in the IVR processed only movements on the X and Y axis, the position of the users' hand did not match the position of a dental handpiece. This might have induced the high standard deviation in the completion time of the tasks, where users who promptly adapted, responded better.

The main advantage of using IVR is to provide a third-dimensional environment for the user, that should be very close to their reality[26]. This authenticity is created by the sensation of immersion and the capacity of faithful reproduction of objects in the third-dimension[30]. Recently, a study reported that dental students who use the stereoscopic feature to view 3D images perform better than their comparison group[31]. This corroborates and may be an indicator of the success of Dental Training to enhance dental education, since IVR has the same plausibility, depending on this technical resource for its existence[32].

One limitation of the study was the lack of a comparison group with another teaching methodology, to assess the motivation to learn this new theme. Accordingly, this motivation might be associated with the novelty factor of the IVR use. Regardless, motivation and engagement are directly related to learning, making IVR a promising resource[33]. Also, the simulator feedback was created with affirmative sentences, not with persuasive interactions, such as questioning the students about the performance that is being held[24], nevertheless obtained positive results in the user experience. Another issue was the lack of evaluation of the influence of the virtual tutor in the students' engagement since we recognize that the auxiliary did not induce a difference in the clinical performance[16]. Additionally, this assessment was not applied in this study, as our aim was not to evaluate the IVR influence on learning.

The growth of IVR in the health education and entertainment field, associated with the arrival of a new generation of students, requires a curricular adaptation of the universities for the use of technologies[34]. In some cases, this delay is associated with the uncertainty of the cost-benefit ratio that IVR brings. In other cases, it is related to the lack of good quality evidence of its positive impact on the learning process. Our findings demonstrate an increase in student motivation when using the IVR, and this might be applied as a strategy for students to feel motivated to conduct studies and practices at home. Also, the development of a new dental simulator using the same scenario and interaction, but with other procedures will provide more resources for these. The feedback of the dental students (regarding the motivation to study while using an IVR and their belief that IVR could increase their engagement to learn) raises important questions about the influence of the IVR in learning skills and retention of information by the students. Thus, the perspective is to carry out a randomized trial to analyze the influence of the simulator on the knowledge of dental students, compared with other teaching methodology.

CONCLUSION

This study described the development of an IVR simulator performing the steps of Content Planning and Device Selection. Undergraduate Dentistry students who used the simulator liked to perform the IVR experience, felt more confident in performing the fixed prosthesis preparation, and desired to have more educational contents through this technological resource. Further studies should be performed to evaluate the inclusion of the IVR in dentistry teaching.

ACKNOWLEDGMENTS

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DISCLOSURE

The authors disclose any financial, economic or professional interests that may have influenced the design, execution or presentation of this work.

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MANUSCRITO II

Immersive virtual reality in fixed dental prosthesis: A proof-of-concept approach for learning.

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ABSTRACT

Purpose/Objectives: This study aimed to realize a proof-of-concept that an immersive virtual reality simulator (IVR) of fixed dental prosthesis could enhance the learning process of undergraduate dental students. Methods: Thirteen first-year undergraduate dental students were assigned into two groups: the G_{VIDEO} group (n = 6) watched a 3D video through a computer, and the G_{IVR} group (n = 7) experimented with a device of virtual reality immersion. Results: Pre- and post-tests were applied to evaluate theoretical knowledge, and the students prepared a fixed dental prosthesis on a mannequin tooth for practical skill. Preparation time, tooth mass, remaining size, and angle of the preparation end were measured. There was a statistically significant difference in theoretical learning between the pre-test and post-test in both groups. However, there was no statistically significant difference between pre-test (G_{Video} 9 ± 1.26 and G_{IVR} 9.57 ± 0.53) and post-test (G_{Video} 10.83 ± 1.16 and G_{IVR} 10.7 ± 0.75) groups. Compared to the group that used the 3D video, there were no differences in the practical skill of the subjects exposed to the IVR simulator for tooth mass (G_{Video} 1.38 ± 0.063, G_{IVR} 1.37 ± 0.09), volume (G_{Video} 520.85 ± 46.71, G_{IVR} 523.11 ± 76.15) or preparation time (G_{Video} 1220.60 ± 547.76, G_{IVR} 1089.43±463.94) of a fixed dental prosthesis in a posterior tooth. Conclusion: The IVR simulator is a promising alternative for undergraduate learning.

Keywords: Immersive virtual reality; Dental education; Fixed dental prosthesis.

INTRODUCTION

Dental practice requires high clinical skills of the dental surgeon[1], and virtual reality (VR) simulation is emerging as an effective training method for the development of these practical skills[2]. The use of this technology to enhance learning has shown positive results for undergraduate students[3], especially due to the resemblance that this technology offers compared to the clinical practice[4] when using 3D environments[5].

Technology is increasingly being applied to health education, but discrepancies have been noted concerning the benefit that VR learning offers to students[6]. The main distinction on quality assessments resides on the feedback provided to the user since success in practical skill is directly related to it[7]. In this way, VR simulation for dental students for restoration processes has shown that skill is acquired similarly to in traditional teaching methods, although VR simulation approaches require fewer interactions and a shorter dialogue time with the tutors[7].

Another relevant issue in VR simulation is the time necessary to carry out the training process. Recently, an experiment evaluated different types of feedback in VR and demonstrated no difference in the execution time of procedures involving wear of structures when the feedback came from the machine, the instructor, or both[8]. However, the same experiment showed that simultaneous feedback from the machine and instructor had a lower procedure error rate. Thus, a simulator with textual and virtual tutor feedback could aid in the learning process of dental students.

The VR dental training proposed in this study is the first IVR simulator for available teaching fixed dental prosthesis. Intended for dentists and undergraduate students, this training allows the preparation for a fixed dental prosthesis in a virtual dental office environment. The preparation of the fixed dental prosthesis is a procedure that requires great practical skill in dentistry. The final anatomy of the preparation requires a series of characteristics that are difficult to obtain for an academic and non-experienced professional, and the VR, as an educational resource, might enhance prosthetic teaching. Thus, this study aimed to realize a proof-of-concept that an immersive virtual reality simulator (IVR) of fixed dental prosthesis could enhance the learning process of undergraduate dental students.

METHODS

VR Dental Training

The IVR resource was developed by the Open University of the Brazilian Public Health System of Universidade Federal de Ciências da Saúde de Porto Alegre in partnership with the Dental Materials Lab from the Universidade Federal do Rio Grande do Sul. The IVR engages the user as the dentist who is responsible for the preparation of the right first lower molar, that will receive a fixed 3-element prosthesis. Another virtual dental surgeon acts as a tutor and works as a dental assistant providing theoretical educational content. The virtual dental surgeon guides the user in the preparation protocol, assisting in the choice of the drills and adjusting the appropriate angulation between the high rotation pen and the tooth.

Design

This study applied the CONSORT Statement to develop the randomized controlled trial (RCT)[9], performed with Dentistry undergraduate students at the Dental Materials Laboratory of the Federal University of Rio Grande do Sul. The inclusion criteria were participation in all stages of the study and not having had previous access to the content. The local Ethics in Research Committee approved the study, and all students signed the consent form (CAAE: 60521416.8.0000.5347).

All current students enrolled in the dental materials course were eligible for this study; thirteen undergraduates were allocated by coin flip to the following two groups: the G_{VIDEO} (n = 6, watching a 3D video on a computer) and G_{IVR} (n = 7, performed the experiment with Oculus Samsung Gear VR). The group distributions are shown in **Figure 1.**

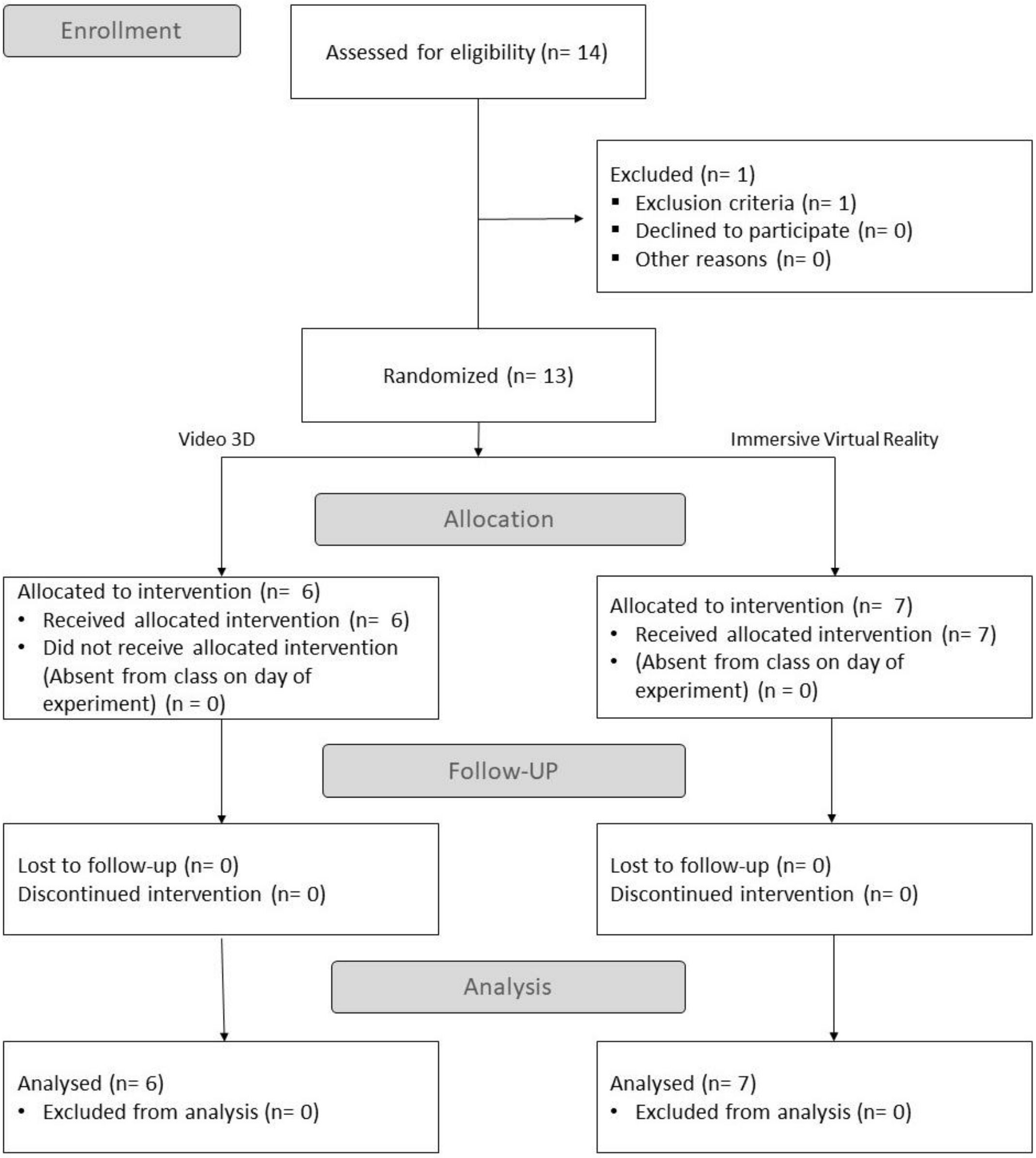

Figure 1. CONSORT flowchart for random assignment of participants.

Development of Immersive Virtual Reality Simulator

The simulator developed for the experiment was submitted on the Samsung Gear VR platform and will be made available free of charge to users. The IVR experience places the student as the dental surgeon responsible for caring for a patient. In this manner, the user should prepare a fixed dental prosthesis on the right first lower molar. A total of 20 tasks were divided into ten steps, applying five diamond tips (1014, 3216, 3195, 3215 and 3216F) from KG Sorensen (Medical Burs Ind. e Com. de Pontas e Brocas Cirúrgicas Ltda, São Paulo, Brazil). **Table 1** shows which diamond tip was used for each step of the preparation.

Table 1. Description of the tasks, steps, and diamond tips used in the Virtual Object in IVR.

Task	Stage	Face	Diamond Tip
1st	Guidance groove	Buccocervical	1014
2nd		Linguocervical	
3rd	Guidance groove	Buccal	3216
4th		Lingual	
5th	Remaining wear	Buccal	
6th		Lingual	
7th	First Wear	Mesial	3195
8th		Distal	
9th	Second Wear	Mesial	3215
10th		Distal	
11th	Guidance groove	Bucco-occlusal	3216
12th		Linguo-occlusal	
13th	Remaining wear	Bucco-occlusal	
14th		Linguo-occlusal	
15th	Guidance groove	Bucco-occlusal	
16th		Linguo-occlusal	
17th	Occlusal finishing	Bucco-occlusal	3216F
18th		Linguo-occlusal	
19th	Finishing the end of the preparation	Buccal	
20th		Lingual	

Assessment

Theoretical Knowledge

The G_{VIDEO} group watched a video on a notebook (MacBook Pro, Apple Inc., CA, USA) with earphones (Harman International Industries, Incorporated, CT, USA), with the same educational content of the IVR, access in https://youtu.be/Q6NghXqJfME. The G_{IVR} group performed the experiment using a Samsung Gear VR Specs, a Samsung joystick, and a headset (Beats Wireless, Apple Inc., CA, USA). To evaluate students' theoretical knowledge, pre- and post-tests were developed. Twelve true or false questions regarding the preparation of a fixed dental prosthesis were applied (SUPPLEMENTAL FILE A). The pre-test was held before the intervention, and the post-test immediately after performing the clinical skill assessment.

Skill Test

After using the IVR or watching the learning object, each student performed a preparation of a fixed dental prosthesis on a mannequin (Prodens, Carapiá Ind. Com. Prod. Odontológicos Ltda, São Gonçalo- Brazil) tooth to evaluate the clinical skill.

A table with a triple syringe, high-speed pen, lighting, and diamond tips was arranged. A mannequin was provided with an artificial right first lower molar to perform the intervention. A prepared tooth was also displayed for the students from both groups. **Figure 2** illustrates the clinical table of each group.

Material quantity and wear time

All teeth were weighed before and after the preparation with a precision scale (AUW220D; Shimadzu, Kyoto, Japan). The calculation to evaluate the amount of wear in each piece was carried out by checking the remaining weight (g) = W0-Wt.

Figure 2. - Clinical table with the material used by G_{IVR} (A) and G_{VIDEO} (B) groups. Healthy tooth and a prepared tooth displayed as a model for each student. D) The user performing the procedure after the intervention (IVR or Video 3D).

Evaluation of the quality of the preparation by MicroCT

The teeth were submitted to microtomography (inspeXio SMX-90CT Plus – Shimadzu, Tokyo, Japan). The teeth were scanned at 70 kV and 100 mA, obtaining 564 images with cuts at every 1 μm. The images were reconstructed in a 3D reconstruction software 3D Slicer (Slicer Solutions, IOWA, USA) where the surface area and dimensions were quantified. Besides the teeth worn out in each group to perform the comparison, three teeth were scanned, and the mean of the results were used as the initial value. Measurements of the coronary wear in the mesiodistal, buccolingual, and cervico-occlusal directions were recorded. Finally, the inclination angle of the preparation end on the four faces of the tooth: mesial, buccal, distal, and lingual were also recorded. **Figure 3** (A-B) shows the evaluation with the ruler tool of the 3D Slicer software.

Evaluation of the angle between the preparation and the tooth

Three sagittal and three coronal sections were obtained through the Micro CT, the sections had a 2-mm spacing between them, always centralized in the teeth, both in the mesiodistal direction and in the buccolingual direction. Images were analyzed in ImageJ (Wayne Rasband, Maryland, USA) software to check the end of the preparation angles. **Figure 3** (C-D) shows the angle evaluation in the ImageJ software. The angle calculation was measured by the angle between the base of the preparation and the axial surface of the tooth.

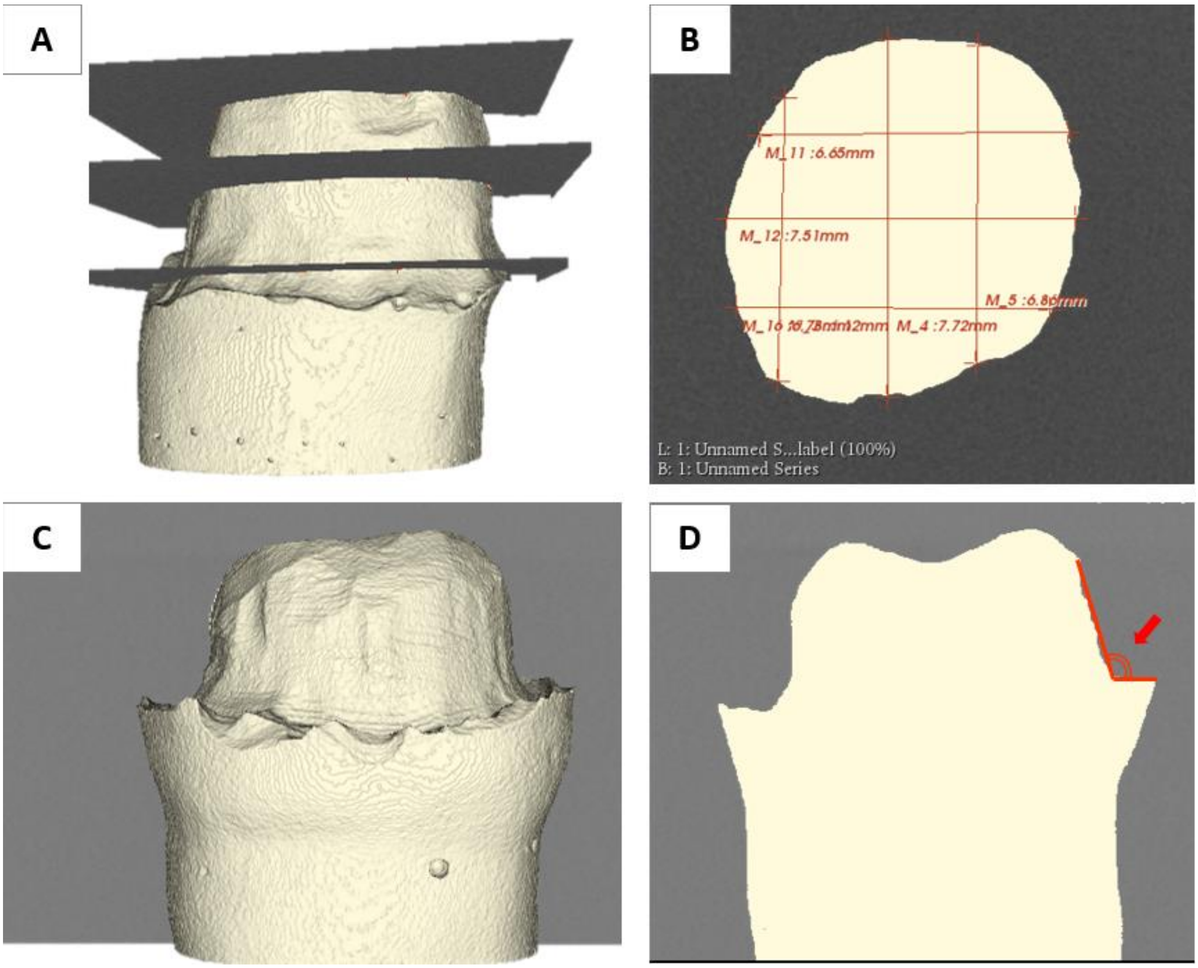

Figure 3. Method used to assess the measurements of the tooth after preparation, and also the angle of the preparation end. **A** - 3 axial cuts with 2mm of spacing. **B** - Intermediate cut with 3 measures in the mesial-distal direction and 3 measures in the

buccolingual direction. **C** and **D** - Coronal section to measure the angle between the end of the preparation and the remainder of the tooth.

Statistical Analysis

A paired t-test was used to compare the pre/posttest theoretical knowledge within the same group. A t-test was used for the analysis between the groups, both in theoretical learning and in clinical skill. To evaluate the tooth height, preparation time and the finishing angle of the preparation, Mann-Whitney nonparametric tests were used. All analysis was performed at a 5% significance level.

RESULTS

A total of six students on G_{VIDEO} and seven students on G_{IVR} were enrolled in the study. **Table 2** shows the characteristics of each group. The G_{VIDEO} group was 66.66% female, while the G_{IVR} group was 42.85% female. There was no difference between gender distribution in the groups (Fisher's exact test $p = 0.400$). The mean age of the participants was 20.33 ± 3.38 for G_{VIDEO} and 19.28 ± 1.38 for G_{IVR}. When questioned about a previous experience on the IVR simulator, 50.00% of the G_{VIDEO} group and 42.85% of the G_{IVR} group answered positively. All participants are on their first course.

Table 2. Characteristics of Dentistry undergraduate enrolled in the randomized trial.

	G_{VIDEO}(n=6)	G_{IVR} (n=7)
Gender		
Female	4 (66.66%)	3 (42.85%)
Male	2 (33.33%)	4 (57.15%)
Age (mean ± sd)	20.33±3.38	19.28±1.38
Schooling		
First Graduate Course	6 (100%)	7 (100%)
Already played another IVR simulator besides VR Dental Training		
Yes	3 (50.00%)	3 (42.85%)
No	3 (50.00%)	4 (57.15%)

Table 3 shows the mean and standard deviation of the theoretical knowledge tests. There was a statistically significant difference between the pre-test and post-test in both the group that used video (G_{Video} 9 ± 1.26 and 10.83 ± 1.16) and the IVR group (G_{IVR} 9.57 ± 0.53 and 10.7 ± 0.75). There was no statistically significant difference between pre-test and post-test groups.

Table 3 - Mean and standard deviation scores of theoretical pre-test and post-test.

	n	Pre-test	Post-test	*p-value*
		Mean±SD	Mean±SD	
$G_{VÍDEO}$	6	9±1.26	10.83±1.16	0.014
G_{IVR}	7	9.57±0.53	10.7±0.75	0.015
p-value		0.149	0.414	

Table 4 shows the mean and standard deviation of measurements of dental structure remaining after preparation in both groups. The measurements were taken in three levels (cervical, middle, and occlusal). No statistical difference was found between groups at any of the levels. Also, the table shows the height between the groups, which also had no statistical difference between the groups.

Table 4 - Mean and standard deviation of the mesiodistal and buccolingual measurement of the remaining dental structure after preparation.

Measurements		Mesiodistal (mm)			Buccolingual (mm)			Height (mm)
		Cervical	middle	Occlusal	Cervical	middle	Occlusal	
	n	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
$G_{VÍDEO}$	6	8.59±0.51	8.16±1.06	6.46±0.73	8.4±0.42	7.0 (1.2)	5.74±0.82	9.7±0.29
G_{IVR}	7	8.40±0.43	8.08±1.50	7.01±1.42	7.97±0.57	6.8 (0.84)	5.89±1.1	9.93±0.67
p-value		0.24	0,94	0.2	0.08	0.37	0.39	0.83

Table 5 shows the mean and standard deviation of the mass (g) ($G_{VÍDEO}$ 1.38 ± 0.063 vs. G_{IVR} 1.37 ± 0.09) and tooth volume (mm³) ($G_{VÍDEO}$ 520.85 ± 46.71 vs. G_{IVR} 523.11 ± 76.15) after preparation in both groups. Regarding the preparation time (m), the mean and standard deviation are presented ($G_{VÍDEO}$ 20.34 ± 9.12 vs. G_{IVR} 18.15 ± 7.734. There was no statistical difference in any comparison.

Table 5 - Mean and standard deviation of tooth mass, volume and time evaluation after preparation.

	n	Tooth mass (g)	Volume (mm³)	Preparation time (m)
		Mean±SD	Mean±SD	Mean±SD
$G_{VÍDEO}$	6	1.383±0.063	520.85±46.71	20.34±7.76
G_{IVR}	7	1.368±0.09	523.11±76.15	18.15±7.73
p-value		0.49	0.47	0.73

Table 6 shows the angle between the end of the preparation and the remainder of the tooth. No statistical difference was found between groups on either side. For the buccal and lingual surfaces, there was no statistical difference when the evaluation of the preparation angle was performed between each face of the tooth.

Table 6 - Mean and standard deviation of the angle (º) between the end of the preparation and the four faces of the tooth.

	n	Buccal angle	Lingual angle	Mesial angle	Distal angle (º)
		Mean±SD	Mean±SD	Mean±SD	Mean±SD
$G_{VÍDEO}$	6	135.44±12.56	142.40±20.83	142.313±18,05	142.31±18,05
G_{IVR}	7	131.82±14.94	147.57±15.03	145.206±24,04	145.20±24,04
p-value		0.73	0.73	0.4	0.48

DISCUSSION

This study evaluated a proof-of-concept that the influence of the experience in IVR in the learning of undergraduate dental students, comparing it to a 3D video on the preparation of a fixed dental prosthesis. The learning was evaluated by theoretical knowledge and practical skills, showing no difference between groups in both assessments. There was no difference between the groups in the characteristics of the dental preparation: time, amount of material removed by weight, and the remaining volume.

Concerning the assessment of theoretical learning, no differences were detected between groups. In another study[2] using a simulator for dental students, it was found that students demonstrated better theoretical performance when exposed to the simulator for more than 8 h. Even though the exact time of simulation exposure to increase theoretical learning is unknown, in our study, the approximate exposure time was 10 min for the G_{VIDEO} groups and 17 min for the G_{IVR} groups, which could contribute to no increase in theoretical assessment. The intervention was evaluated transversally, and the knowledge retention was not evaluated longitudinally. Although the use of VR has shown positive results when evaluated in the long term[10], long-term evaluation should be realized in future studies.

The sample used in this study was composed of undergraduate dental students with no experience using high rotation pen and fixed dental prosthesis preparation. VR has been shown to be more appropriate for specialist professionals who had greater knowledge retained[11] and practical skill[12], when compared to general practitioners and newly qualified dentists. The IVR simulator might have greater effectiveness in more experienced professionals when learning new protocols and preparation designs.

Although a shorter time spent preparing might have advantages, such as lower patient anxiety and greater capacity to attend patients. In the present study, there was no difference in time and quality of preparation between groups. However, a possible association between the time spent preparing and the quality of the preparation should be considered, as in another study the group that used VR prepared with superior quality in a longer time[13], due to the feedback time of the simulator.

In the present study, the ideal wear was approximately 1 mm on the axial and lingual surfaces, 1.5 mm on the buccal, and 1.5–2 mm on the occlusal face. Both the amount of remaining mass and the volume of the surface area showed no difference between the groups. However, except for the cervical portion with derisive wear, the mean face values were adequate. Another study evaluated the amount of tooth worn in the coronary access and showed that VR group obtained better results, with lower wear and, therefore, better clinical conduct[14].

Also, the mesiodistal and buccolingual dimension in the three levels (cervical, middle and occlusal) showed no difference between the 3D and IVR groups. In this study, the IVR feature does not indicate that practical skill was improved when compared to 3D video. These results might be due to the similar graphical quality of the 3D and IVR produced since the graphics quality of the educational material might be related to the improvement of clinical performance[5]. In the present study, immersion did not influence the students' practical skill. Also, the angle of the end of the preparation was not influenced by the interventions. Both groups failed to perform adequately since the appropriate angle is considered to be 95 to 101°[15]. While in the G_{VIDEO} and G_{VR} groups, this angle was greater than 130°.

A limitation of this study is the lack of evaluation of the equivalence between learning. A comparison group with the teacher demonstration should have been conducted to simulate the method that is most used today in the courses. Although it is known that there is equivalence when compared learning by video and teacher demonstration[16].

The inclusion of new technologies in dental teaching can enhance learning[17], but the exclusive use of IVR is insufficient for complete learning[6]. The IVR, through its concept of stereoscopic visualization, improves the understanding of dental undergraduate students[18]. However, we acknowledge that one of the great difficulties of teachers is how to insert ICT (Information and Communication Technology) in traditional teaching. Thus, it is necessary to discuss how and when to insert technology in dental education[2].

CONCLUSION

There is no difference in theoretical learning and practical skill in dental students when exposed to an IVR learning object compared to a group watching a 3D video on the preparation of a fixed dental prosthesis in a posterior tooth.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

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SUPPLEMENTAL FILE A

Questions of pre and posttest of theoretical knowledge.

1. (V) The fixed dental prosthesis of 3-elements is indicated when the patient has an absent tooth space and two teeth adjacent to this free space.
2. (V) The grooves orientation are guides to the complete removal of the enamel remainder of the teeth.
3. (F) Grooves orientation should be performed only on the occlusal and buccal surfaces.
4. (V) On the occlusal surface, the orientation grooves should follow the inclination of the cusps and the occlusal slopes.
5. (V) On the occlusal surface, the penetration depth of the drill should be at least 1.5 cm.
6. (V) The cervical guidance groove is an important step to preserve an adequate preparation.
7. (F) The preparation of fixed dental prosthesis on tooth 46 should be done with only one diamond tip.
8. (V) The metal matrix has the function of protecting the tooth adjacent to the prepared tooth.
9. (F) The preparation depth depends only on the patient's pain sensitivity.
10. (V) The axial surface inclination, after preparation, should be expulsive to facilitate insertion of the prosthesis.
11. (F) The finishing of the preparation is optional; it is a dentist caprice that performs this procedure.
12. (V) The finish of the preparation has the function of leaving the prosthesis with better adaptation at the moment of cementation.

4 CONSIDERAÇÕES FINAIS

O uso de simuladores voltados ao ensino de Odontologia é uma prática comum em Universidades que dispõe de maior investimento financeiro. A utilização de simuladores como o Haptic (Moog Inc, NY, USA) e DentSim (DentSim Ltd, NY, USA) têm mostrado evidências positivas quanto a sua inserção como recurso complementar à sala de aula (De Boer *et al*., 2016; Girod *et al*., 2016). Entretanto, é preciso refletir sobre a viabilidade da implantação desses sistemas que necessitam hardwares e softwares de elevado desempenho, e por consequência, alto investimento para as Universidades de países em desenvolvimento, como o Brasil.

Na perspectiva de acompanhar os modelos de inovação, onde o uso das tecnologias da informação e comunicação possibilitam o desenvolvimento de softwares e a sua escalabilidade através dos dispositivos móveis, o VR Dental Training vem a ser uma alternativa como simulador. Priorizando a viabilidade de aplicação em sala de aula com a redução de aproximadamente 80% do investimento necessário, quando comparado aos simuladores não imersivos consolidados no mercado mundial.

Além disso, o conceito de implementar um simulador a um smartphone gera valor para ambos, por não exigir o elevado investimento em um dispositivo com apenas um fim. Essa concepção vai ao encontro das definições de economicidade, onde é requerido um menor investimento para o desenvolvimento de uma solução com a mesma eficiência. Nesse sentido, se faz jus o investimento na pesquisa de desenvolvimento e avaliação desses recursos em RVI, uma vez que essa tecnologia é uma tendência para o ensino na saúde, mesmo que com eficiência ainda incipiente.

A RVI permite um elevado grau de imersão do usuário, com ganho de aprendizagem semelhante ao uso de vídeos, recurso educacional de alta prevalência nas gerações atuais. Um dos seus trunfos é a questão da novidade do recurso, que desperta curiosidade e favorece o engajamento, pois em uma análise subjetiva realizada durante o desenvolvimento neste trabalho, a primeira reação dos alunos foi de surpresa quanto a qualidade e verossimilhança com a realidade.

Esse feedback positivo dos alunos durante o experimento vai ao encontro do fato da RVI despertar no aluno interesse do recurso educacional devido à qualidade da experiência que a tecnologia proporciona. Essa plausibilidade deve ser explorada, uma vez que o ensino centrado no aprendiz se faz cada vez mais necessário em salas de aula.

Outra vantagem em utilizar a RVI para o ensino é a possibilidade de incorporação de outras tecnologias associadas ao simulador, como a Inteligência Artificial (IA). Caracterizada como uma ciência computacional que visa o entendimento e desenvolvimento de propriedades de inteligência (Panch *et al*., 2018) tem no *machine learning* uma subcategoria já utilizada na área da saúde (Seligman et al., 2018), mas que ainda não possui relatos no ensino de Odontologia. É baseado em um modelo preditivo que é gerado a partir de dados prévios fornecidos pelos comportamentos dos usuários. Com o aprimoramento dos simuladores e a elevada capacidade de transferência de dados digitais em tempo real, a evolução tecnológica caminha na direção da criação de algoritmos personalizados para cada aluno, onde o feedback poderá ser instantâneo e individual de acordo com sua necessidade. Para isso, o investimento na RVI deve ser não somente gráfico e conceitual, mas também em desenvolvimento científico e tecnológico, trabalhando com o aprimorando de hardwares com elevada capacidade de processamento, para assim, desenvolver softwares com IA de qualidade.

Ainda, a possibilidade de realizar uma estratégia de análise de grandes bancos de dados (*data mining)*, que consiste na busca pelo conhecimento do comportamento do usuário através do estabelecimento de padrões de suas ações (Han J., 2011). A análise dos padrões poderá nos levar a criação de hipóteses, auxiliando tanto no aprimoramento de softwares de RVI, quanto na metodologia das pesquisas que serão desenvolvidas a partir dessa mineração dos dados produzidos pelos usuários. Esse investimento em tecnologia está ocorrendo em larga escala nas diversas áreas do conhecimento, sendo o ensino na saúde um candidato em potencial para receber essas tecnologias em sua rotina.

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