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Virtual Preparations Versus Classic Preparations on Resin Models in Prosthodontics

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Abstract *Virtual reality technologies are important auxiliary tools in the process of learning and acquiring the manual skills necessary for clinical maneuvers in dental prosthodontics. This study shows the particularities in the use of the virtual simulation system designed for dental prosthodontics, compared to the classically preparations performed on resin models. The interactively simulation systems reproduce real clinical situations in which students practice specific dental prosthetics maneuvers. Resin models do not reproduce the accuracy of the dental structures at the time of the preparation. The advantages of using virtual technology are efficient clinical training, allowing for repeatability, self-assessment of procedures and the acquisition of manual skills. In this way, the advantages conferred by virtual simulators are superior to those resulting from the use of resin models in the acquirement of manual skills.*

Keywords*: resin models, dental preparations, virtual technology, haptic device*

1. Introduction

Acquiring the skills to perform dental procedures, specific to dental prosthodontics, is essential for students. Up to now, they are accumulated in the laboratories of dental faculties in two stages.

In the first, students are trained on gypsum or resin models with artificial teeth or on phantom heads using real dental instruments (burs), etc. Artificial models cannot provide the level of detail and properties of dental tissues. Artificial teeth that reproduce the features of natural teeth may overcome these limitations. In recent years, different factory-manufactured models have been introduced in the market, which are realistic and standardized. Also, these modes present with ideal teeth morphology and conditions, restricting teaching to standard preparations which is not always encountered in patients.

In the second stage, students perform clinical procedures on patients under the supervision of teachers. So students go through a process of trial and error to gain experience and safety in medical procedures. For this reason, haptic feedback interfaces have been introduced between the two stages of training with good results and fewer medical errors [1]. Instead of using real burs on patients, the student has the stylus of the haptic device, which has a virtual 3D representation, models of real dental tools (burs) and performs movements on virtual models of teeth. Depending on the simulated dental procedure, the feedback of the employed simulator is represented by the topological changes of the tooth structure or forces (sensations) in the user's hand. The sensations are similar to those felt by the user, when performing the same dental procedure on a patient [2]. Medical practice has been limited to patients in recent years and for this reason the need to implement virtual reality technology has emerged [3].

Virtual reality technologies have been introduced in dental medical education, respectively also in dental prosthetics as complementary resources of the learning process. The virtual reality system has an important role in the teaching and training process in dental prosthetics. Virtual reality technologies can be incorporated into e-learning platforms [4]. The haptic technology is the most used technology, especially in maneuvers that require tooth preparations [5].

The technology of simulation systems (haptic technology and virtual reality) designed for the training of dental procedures, has been introduced into university curricula [6]. The major advantage of using

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virtual simulation consists in the possibility for students to acquire effective knowledge in a short time [7].

Students can acquire prosthetics knowledges and perform simulations of dental preparations, specific to dental prosthetics in a virtual environment, with a realistic sense of touch, using virtual reality technologies. Dental preparations made with virtual technology can be evaluated and repeated with appropriate feedback [8]. The learning tool is realistic thanks to the use of haptic technology that allows an adequate force feedback. The feedback force is similar to that of practicing on the teeth [9].

Repeated procedures lead to the acquisition of manual skills [10]. Another study showed that dental students using computerized virtual simulation were found to learn procedures faster than those using traditional methods and have superior skill levels [11].

By evaluating the students who used the virtual simulator for dental preparations, the average responses were obtained (on a scale from 1 to 5): improves manual skills 5, increases speed 5, accurate evaluation 3.29 [12].

2. Materials and methods

This study evaluates the effectiveness of the virtual simulation system, applied to partial framework denture preparations, compared to the same preparations made on resin models. The intended preparations are for occlusal rest seats (on lateral teeth) and supracingular rest seats (on canines) in order to apply the partial framework denture.

The study was carried out within the testing stages of the virtual simulation model designed for dental prosthetics within the research project "Virtual e-learning platform based on 3D applications, usable in dental prosthetics".

For the treatment with partial framework denture, it is important to select the abutment teeth. The main abutment teeth, adjacent to the edentulous areas are the ones on which the anchoring elements of the partial framework denture are positioned. The secondary or indirect abutment teeth are the ones on which the auxiliary rests are applied, as counter-tipping elements. The preparation of the direct or indirect abutment teeth, on which the rest seats are materialized, is planned on the study models, after the plan of the prosthesis has been made.

The preparations were performed in a similar manner, both virtually and classically on resin models.

To practice the maneuvers in the virtual environment or on resin models, the protocol for the preparation of occlusal and supracingular rest seats was used.

Preparation protocol for occlusal rest seats (Figure 1):

Maneuvers: occlusal rest seats

Tools: spherical diamond burs

Theoretical notions:

- the preparation of seat is done on the occlusal surface in the enamel, next to the marginal fissures (mesial or distal) and with the grinding of the marginal ridge
- the bur is held at a 90 degree angle
- the shape of the rest seat is hemispherical
- rest thickness 1 -1.5 mm
- the size of the occlusal rest (the length is 1/4 of the mesio-distal length of the tooth and the width is 1/3 of the vestibulo-oral width).

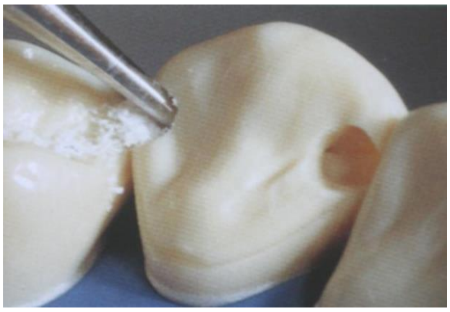

Figure 1. Preparation of the occlusal rest seats on model

Preparation protocol for supracingular rest seats (Figure 2):
Maneuvers: supracingular rest seats
Tools: cylindrical diamond burs with a rounded head
Theoretical notions:
- the preparation of the seat is done in enamel
- the rest seat has the shape of a supracingular step
- it starts from the side of the marginal ridge to the opposite marginal ridge
- the bur is held in the axis of the tooth
- the width of the seat is 1 mm.

Figure 2. Preparing the supracingular rest seat on model

Students use gypsum or plastic models to practice rest seats before preparing them on patients. Plastic models used in current practice have plastic or resin teeth and are used by students as well as in hands-on courses for various dental prosthetic preparations.

Resin tooth models have tooth consistency similar to tooth structures. The hardness of the tooth material is similar to the hardness of enamel and dentine.

Models with plastic teeth (acrylate) are cheaper and easier to use, but do not give the accuracy of the preparations in the tooth structures. Acrylate is a macromolecular material with very little resistance to breaking, bending and abrasion. Teeth made of acrylic resins have a dense, homogeneous structure, have mechanical resistance, glossy surfaces, it wears off over time. Reduced hardness is determined by an increased coefficient of abrasion.

Dental models obtained by 3D printing can also be used. Both regular teaching of dentistry students and various training schemes for dentists primarily make use of the series teeth models, resin blocks, or extracted teeth, whereas the 3D teeth models may well offer an alternative in this respect. The 3D printed teeth models developed for teaching purposes are used in various areas of dentistry. Their overall usefulness in acquiring the necessary hands-on skills for clinical work was acknowledged in all the studies under review, regardless of a specific procedure at issue. The 3D printed teeth models provide an alternative to the extracted ones, and the series teeth models in regular teaching practice. Nonetheless, the major criticism of 3D-printed teeth is the difference in radiopacity and hardness between resin and human dentine [13, 14].

For the comparison of occlusal preparations, the hardness of the artificial teeth of the resin models is relevant. The hardness of a plastic generally refers to the ability of a plastic material to withstand compression force. There are ways to modify the hardness of a plastic material by mixing a high hardness resin into a low hardness resin to increase its overall hardness. Commonly used mixed resins are: PS, PMMA, ABS and MF.

The virtual preparations of occlusal and supracingular rest seats were made with the virtual simulation system.

The proposed model for dental prosthetics simulates the execution of clinical maneuvers for dental preparations based on grinding-reduction of dental tissues, using user interaction with a 3D environment using a haptic device [15, 16].

From the point of view of the development environment, after studying the solutions available on the market, the Unity platform was chosen, which allows the porting of stand-alone applications in a compatible web format. The hardware is composed of a graphics station and a 3D monitor for running the application and its stereo visualization, completed with a Geomagic Touch haptic device for obtaining tactile feedback. The instruments are represented by haptic devices that can be moved on three axes and offer tactile feedback very close to reality. Haptic devices add tactile sensation to the human computer interaction process and play an important role in enhancing the sensation of immersion.

Haptic technology is that which presents an interface that can be accessed by a user by means of a simple touch applying force, vibrations and/or movement. The rendering of the tactile sense is given by the reaction force, which will be felt by the user through the stylus of the haptic device. 3D glasses allow the viewing of three-dimensional images and are compatible with the implemented technology. The user benefits from interaction devices: geomagic touch haptics, keyboard, mouse. The working base is composed of laser-scanned models and teeth (properties). The tooling is conferred by burs. The graphic interface is provided by the haptic library. The OpenHaptics library was used for the virtual simulation. The simulation software includes graphic rendering and haptic rendering, vibrations, audio effect, tactile feedback [17, 18].

The 3D models that will be used in the dental prosthetics software were created to exemplify the different types of manovers specific to this field (Figure 3). In order to replicate in the virtual environment a series of real and representative case studies, as well as integral arches, the digitization method - laser scanning - was chosen. The quality of 3D models is essential for dental simulation.

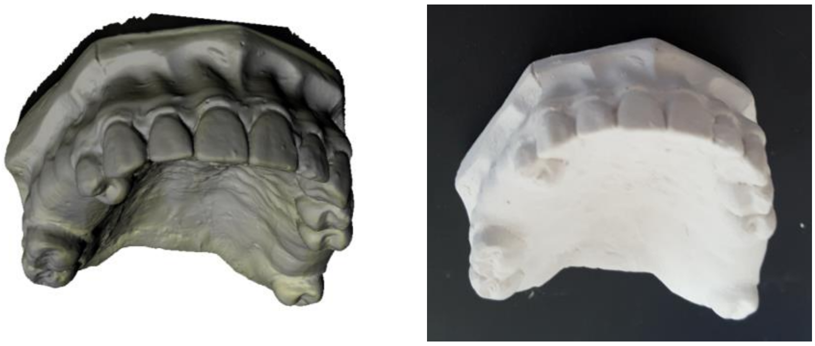

Figure 3 Virtual model vs gypsum model

The factors that condition the simulation are: the data and the structure of the tooth (enamel and dentin), the biomechanical properties, the model used to evaluate the forces for feedback. The biomechanical properties of the tooth, conclusive for simulations, are focus on the modulus of elasticity and its hardness.

The hardness coefficients (GPa) for enamel is 4.88 ± 0.35 and for dentine is 0.92 ± 0.11. The elasticity of modulus coefficients enamel (GPa) is 80.35 ± 7.71 and for dentine is 19.89 ± 1.92 [19].

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The prosthodontics simulator application scene is as follows. The system allows simulations on both models and the patient (Figure 4). Clinical procedures refer to the preparation of the occlusal or supracingular rest seats, the preparation of the guiding surfaces, the reduction of the occlusal surface of migrated teeth and the grinding of the tooth for the metal-ceramic crown. The application scenery allows changing the position of the model or tilting the patient's head. The application scenery can zoom in or out. The clinical cases show particular clinical situations (class I edentulos for example) or complete arches. Dental instruments, probe, mirror, high-speed hand piece are used. Six types of burs are used. The soft allows the repeatability of the maneuver, by returning to the intact occlusal surface. When the application is restarted, subsequent preparations are deleted. By pressing the haptic button, the preparation starts (Figure 5). The system benefits from graphics stations, 3D glasses, keyboards, mouse, haptic devices.

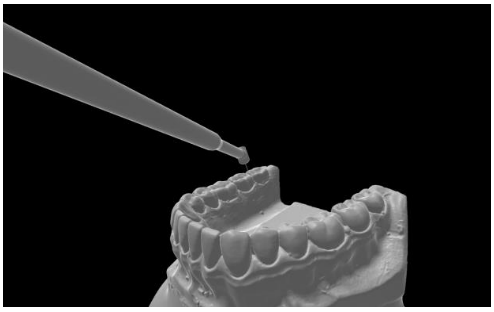

Figure 4. The scenarios taken into account
when developing the application - the first option

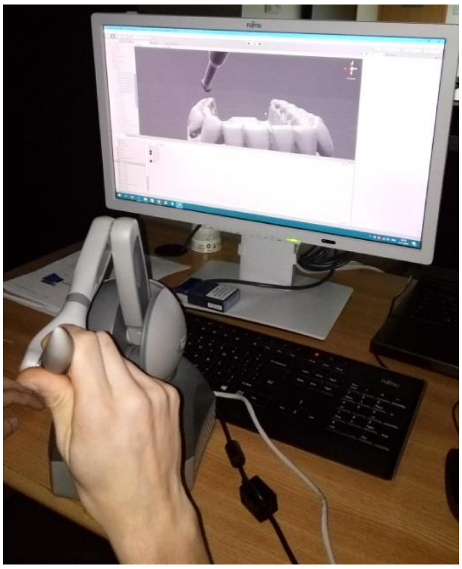

Figure 5. Testing the scenarios using
the haptic device - the first option

3. Results and discussions

A virtual dental simulation environment with a haptic device is devised and developed. By the integration of the haptic device the user can touch and modify the structures modeled in the environment. The stereovision capability provides more realistic visualization with depth information of the objects by creating 3D images.

Teeth preparations for rest seats require knowledges of the diamond burs used, the dimensions of the preparations, checking their correctness.

In the test stage of the virtual simulation model, different levels of sensitivity of the haptic device were programmed for the two dental layers so that in the final application the difference felt with the specific instrumentation of dental prosthetics could be recreated as faithfully as possible. Since the haptic device has a shorter tip than the instruments normally used, a special tip was designed that is mounted on the haptic device **(**Figure 6) in order to perform some edifying tests in this sense. Thus, the tip of the haptic device was digitized and an additional tip was modeled in Catia V5, manufactured later with the help of a 3D printer.

Figure 6. The modified haptic device (a) and (b)

The tests carried out did not highlight significant advantages of this way of working, so in the final version of the system this tip will not be used or it will be an optional one. Since during a simulated maneuvers in the virtual environment the student is focused on what is displayed on the monitor, the plastic tip is not an indispensable accessory (Table 1).

Table 1. Preparation time with the haptic device versus the modified haptic device

Test	Arcade	Preparation time with haptic (min)	Preparation time with modified haptic (min)
1	Mandible	4:10	4:08
2	Mandible	3:20	3:17
3	Mandible	5:00	4:56
4	Mandible	4:30	4:27
5	Maxillary	3:40	3:37
6	Maxillary	4:50	4:48
7	Maxillary	4:20	4:17
8	Maxillary	5:00	4:57

The evaluation of effectiveness of the virtual simulation system it was realized when measuring few parameters. The efficiency of the virtual system was reported when measuring preparation times for occlusal and supracingular rest seats at maxillary and mandible. The same preparations were similarly evaluated on resin models. The assessment is reported and at correctness of virtual preparations versus model preparations.

The user have a documentation to explain the software. The functions of the program described in the documentation are accomplished by the user. Also, a period of time is allowed to the user to adjust a comfortable position. A period of time, in minutes, is allowed to the user to prepare the rest seats.

Compared to the simulation system, a period of time was required for the adaptation to the virtual frame, as well as repeated maneuvers for positioning the burs in the frame, respectively near the marginal fissures, as well as for making virtual contact between bur and tooth. Virtual preparation allows the repeatability of the maneuver to learn it and to achieve maximum accuracy. Preparations in the mandible are virtually easier than those in the maxillary.

Preparations in quadrants 3 and 4 require less preparation time compared to those in quadrants 1 and 2 (Table 2). The preparations provide adequate feedback, similar to the sensation experienced in the preparation of enamel and dentin. The reaction force felt by the user is greater in enamel. The system offers the possibility of appreciating the limits of correct preparations only in enamel, or exceeding them in dentin, through color changes. Thus students can self-evaluate the preparations.

Preparations on models are easier to perform than virtual ones, but they do not allow the repeatability of the maneuver. The accuracy of preparations on models is lower than in the case of virtual preparations. The reasons for the approach in implementing the application based on virtual reality technology are the following: area of interest, constituting a very great preoccupation , easy access to information, preparing students before a real patient, compared to previous dental simulations, it focuses on specific elements of dental prosthetics, precise and efficient, help to develop the manual skills of users [20, 21]. The achieved goals of using the virtual environment are: university work environment, clear interface, repeatability, stable haptic feedback forces.

Students can acquire prosthetics knowledges and perform simulations of dental preparations, specific to dental prosthetics in a virtual environment, with a realistic sense of touch, using virtual reality technologies.

Table 2. Evaluation of maxillary preparations for occlusal and supracingular rest seats

Test	Maxillary	Preparation time virtual (min)	Preparation time per model (min)	Correctness of virtual preparation (%)	Correctness of preparation per model (%)
1	Quadrant 1	3:40	3:10	98.5	95.5
2	Quadrant 2	4:50	3:50	94.2	90.2
3	Quadrant 1	4:50	4:00	94.2	92.2
4	Quadrant 2	4:15	4:10	87.5	85.5
5	Quadrant 1	4:10	3:50	86.2	85.2
6	Quadrant 2	4:20	4:00	84.7	82.7
7	Quadrant 1	5:00	4:10	95.3	91.3
8	Quadran 2	5:00	4:20	94.2	92.2

Rest seats preparations are done faster on models, while the time interval in the virtual environment is longer. The difference in time is approximately 1-1.5 min (Table 3). The correctness of preparations, expressed in percentages, is higher in the virtual environment. The explanation comes from the fact that, virtually, the system allows the repeatability of the work and the saving of previous preparations, with the aim of acquiring manual skills.

Table 3. Evaluation of mandible preparation for occlusal and supracingular rest seats

Test	Mandible	Preparation time virtual (min)	Preparation time per model (min)	Correctness of virtual preparation (%)	Correctness of preparation per model (%)
1	Quadrant 3	4:10	3:40	86.2	84.2
2	Quadrant 4	3:20	3:00	91.8	90.8
3	Quadrant 3	5:00	5:20	94.5	91.5
4	Quadrant 4	3:30	3:10	87.8	82.8
5	Quadrant 3	4:20	4:00	89.4	85.4
6	Quadrant 4	4:10	3:50	90.5	86.5
7	Quadrant 3	4:30	4:10	92.6	85.6
8	Quadrant 4	4:20	4:00	94.6	84.6

Although the virtual simulation system is more expensive compared to the classic methods of preparations on resin models, it is more efficient in time (Figure 7**)** due to the possibility of practicing and repeating the preparations, until they are learned correctly [22, 23]. Also, the system allows the self-evaluation of the work and an appropriate feedback.

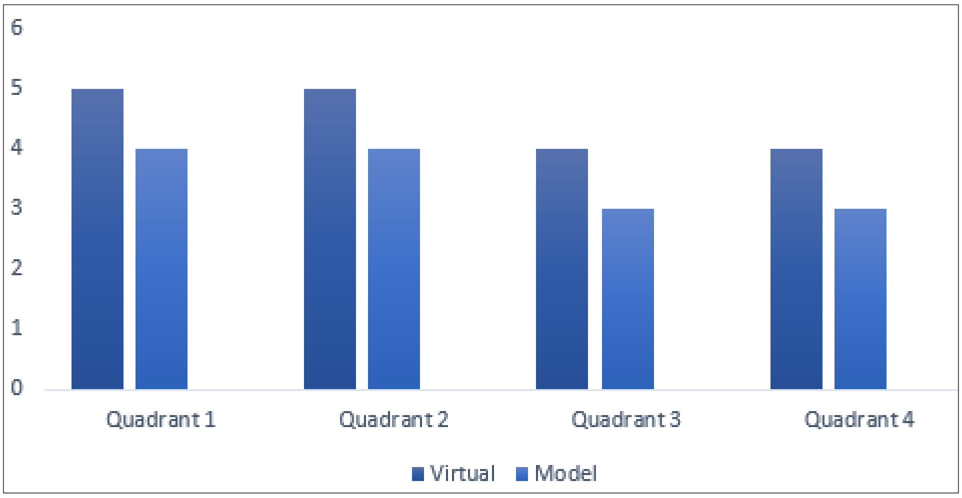

Figure 7. Effectiveness of virtual versus model preparations

Dental simulations supported by haptic feedback gained superiority over traditional methods [24].

A retrospective study compared the results of two groups of students, one who used a virtual reality simulator and one with traditional phantom head learning. The abilities of students who used virtual reality was higher than those who had traditional learning [25].

The specialized studies regarding the preparations for ceramic crowns on the model or in the virtual environment show that 96.97% of the students agree with the clinical benefits of the virtual system [26].

Another studies about cavity preparation with virtual simulator indicates significant better performance despite lower scores reported with increased difficulty [27].

A study for assessing the virtual preparation of 2 mm depth cavities in enamel showed the improvement of operator skills, through qualitative feedback [28].

Additional studies focused on students who used virtual reality for several years show that they learned faster and had more confidence with a high-speed hand piece after virtual training [29].

Other studies related to the cavity preparations with a virtual simulator or on plastic models show improvement in the drilling skill of both groups with insignificant differences [30].

Another study showed that virtual reality improved the acquisition of dental manual skills even in short periods of training and retention of theoretical knowledge [31].

Haptic technology provides sense of touch and force feedback of dental structures. It also helped the students to obtain preparation accuracy, shortened the preparation time in the first stages of the training and augmented the traditional approach [32].

The virtual simulator reduced the anxiety associated with the real patient treatment [33].

In the performance of virtual reality technology assessment, the cost-benefit ratio of simulations offers advantages [34, 35]. Among them are some of the advantages over traditional training methods, automatic performance evaluation, repeatability of application, use of data, ability to create scenarios and simultaneous use of the same scenario, etc.

4. Conclusions

Virtual reality systems for dental prosthetics are tools for learning and practicing common clinical maneuvers, additional to courses and practical training. Virtual reality technologies applied in current practice improve the ways of accumulating knowledges and facilitate the training of students, or resident doctors, without affecting the patients.

Virtual preparations offer users the advantage of obtaining dexterity, through the repeatability of maneuvers, in a 3D rendering manner, compared to preparations made on resin models.

Resin models do not reproduce the accuracy of the dental structures at the time of the preparation of the rest seats.

The advantages of using virtual technology are efficient clinical training, allowing for repeatability, self-assessment of procedures and the acquisition of manual skills. In this way, the advantages conferred by virtual simulators are superior to those resulting from the use of resin models in the acquisition of manual skills. The virtual simulation system designed for dental prosthetics is an auxiliary tool for learning, assessment and the acquisition of manual skills.

References

1.USMAN J., ANDONISSAMY L., ELSIRINT A., Boon of Virtual Reality and its Applications as an Educational Tool in Dentistry: A Review, *Int. J. Pharm.*, 5(3), 2015, 680-684.
2.NARA N., BEPPU M., TOHDA S., SUZUKI T., The introduction and effectiveness of simulation-based learning in medical education, *Internal Medicine* 48, 2009, 1515-1519.
3.FEENEY L., REYNOLDS P.A., EATON K.A., HARPER J., A description of the new technologies used in transforming dental education, *British Dental Journal* 204, 2008, 19-28.
4.*** DentSim Overview, Accessed (2011 Apr 4) at: www.denx.com/ DentSim/overview.html
5.*** Iowa Dental Surgical Simulator, A collaboration between the University of Iowa College of Dentistry and the GROK Lab. Accessed (2011 Jan 7) at:
http:// grok.ecn.uiowa.edu/Projects/medsim.html
6.LUCIANO C., BANERJEE P., DEFANTI T., Haptics-based virtual reality periodontal training simulator, *Virtual Reality*, 2(13), 2009, 69-85.
7.SHARAF B., LEVINE J.P., HIRSCH D.L., BASTIDAS J.A., SCHIFF B.A., GARFEIN E.S., Importance of computer-aided design and manufacturing technology in the multidisciplinary approach to head and neck reconstruction, *Journal of Craniofacial Surgery*, 21, 2010, 1277-1280.
8.SANDU S.A., NEAMŢU C.D., GRIGORESCU S.D., BĂNICĂ C. K., BABIUC I., BISOC A., CONSTANTINOVICI A., Utilizarea tehnologiei de realitate virtuală în protetica dentară. *Ro J Stomatol*, LXI (2), 2015, 121-125.
9.SANDU S.A., NEAMȚU C.D., GRIGORESCU S.D., PĂVĂLOIU I.B., Sistemul de simulare virtuală pentru protetica dentară. Partea I, *Ro J Stomatol*, Nr., (LXIII) 2, 2017, 67-72.
10.PĂVĂLOIU I.B., IOANIŢESCU R., DRĂGOI G., GRIGORESCU S., SANDU S.A., Virtual reality for education and training in dentistry, *the 12th International Scientific Conference elearning and software for education Bucharest*, april 21-22, 2016 10.12753/2066-026x-16-052
11.PAVALOIU I.B., SANDU S.A., GRIGORESCU S., DRAGOI G., Inexpensive dentistry training using virtual reality tools, *Proceedings of inted 2016 Conference 7th-9th* march 2016, Valencia, Spain isbn: 978-84-608-5617-7
12.POHLENZ P., GRÖBE A., PETERSIK A., VON STERNBERG N., PFL ESSER B., POMMERT A., et al. Virtual dental surgery as a new educational tool in dental school, *Journal of Cranio-Maxillo-facial Surgery*, 38, 2010, 560-564.
13. REES J.S., JENKINS S.M., JAMES T., DUMMER P.M.H., BRYANT S., HAYES S.J., et. al., An initial evaluation of virtual reality simulation in teaching pre-clinical operative dentistry in UK setting, *European Journal of Prosthodontic and Restorative Dentistry*, 15, 2007, 92-98.
14.CURNIER F., Teaching dentistry by means of virtual reality – the Geneva project, *International Journal of Computerized Dentistry* 2010; 13: 251-263.
15.JODA T., GALLUCCI G.O., WISMEIJER D., ZITZMANN N.U., Augmented and virtual reality in dental medicine: A systematic review., *Comput. Biol. Med.*, 2019,108:93-100.
16. *** http://www.sensable.com/products-openhaptics-toolkit.htm
17.NEAMTU C., GALIS M., HURGOIU D., POPA A., Using Virtual Reality for Creating (e)Learning Enviroments – *International Conference: Further Education in the Balkan Countries*, 23-25 October, 2008, Konya, Turcia, pg. 181-189, ISBN 978-975-8890-69-9, vol. I
18.SCHÖNWETTER D.J., REYNOLDS P.A., EATON K.A., DE VRIES J., Online learning in dentistry: an overview of the future direction for dental education. *Journal of Oral Rehabilitation* 37, 20109, 27-940.

19.HADEN N.K., HENDRICSON W.D., KASSEBAUM D.K., RANNEY R.R., WEINSTEIN G., ANDERSON E.L., et. al., Curriculum change in dental education, 2003-09, *Journal of Dental Education* 74, 2010, 539-57.
20.WELK A., SPLIETH C., WIERINCK E., GILPATRICK R.O., MAYER G., Computer-assisted learning and simulation systems in dentistry - a challenge to society, *International Journal of Community Dentistry* 9, 2006, 253-265.
21.SAN DIEGO J.P., MCANDREW P., The feasibility of capturing learner interactions based on logs informed by eye-tracking and remote observational studies, *Journal of Interactive Media in Education* 4, 2009, 1-15.
22.SAGHIRI M.A., VAKHNOVETSKY J., NADERSHAHI N., Scoping review of artificial intelligence and immersive digital tools in dental education, *J Dent Educ*., 2022, 86(6):736-750.
23.BRUSCO, N., ANDREETTO M., LUCCHESE L., CARMIGNATO S., CORTELAZZO G. M., Metrological validation for 3D modeling of dental plaster casts, *Medical Engineering and Physics Volume*: 29 (9), 2007, 954-966
24. HAYASHI, K., SACHDEVA A. U. C., SAITOH S., LEE S. P., KUBOTA T., MIZOGUCHI I., Assessment of the accuracy and reliability of new 3-dimensional scanning devices, *American Journal of Orthodontics and Dentofacial Orthopedics Volume*: 144(4), 2013, 619-625
25.LIU G., ZHANG Y., WANG D., Cutting Force Model of Dental Training System., *In Proceeding of IEEE IROS* 2005, *925-929*.
26. BALIJEPALLI A., KESAVADAS T., A Haptic Based Virtual Grinding Tool, *IEEE Virtual Reality Symposium* 2003, March 22-26, Los Angeles, CA.
27. MOUSSA R., ALGHAZALY A.R., BORZANGY S., Effectiveness of Virtual Reality and Interactive Simulators on Dental Education Outcomes: Systematic Review, *Eur. J. Dent.* 2022, 16(1):14-31.
28. LIU L, ZHOU R, YUAN S, et.al., Simulation training for ceramic crown preparation in the dental setting using a virtual educational system, *Eur. J. Dent. Educ.* 2020;24(2):199-206
29.AL-SAUD L.M., MUSHTAQ F., MANN R.P., et. al., Early assessment with a virtual reality haptic simulator predicts performance in clinical practice, *BMJ Simul Technol Enhanc Learn* 2020;6(5):274-278
30.LIN W.S., CHOU J.C., CHARETTE J.R., METZ M.J., HARRIS B.T., CHOI N., Creating virtual 3-dimensional models for teaching pre-clinical tooth preparation: Students' usages and perceptions. *Eur J Dent Educ* 2018;22(3):e573-e581
31. AL-SAUD L.M., MUSHTAQ F., ALLSOP M.J., et. al., Feedback and motor skill acquisition using a haptic dental simulator, *Eur. J. Dent. Educ.* 2017;21(4):240-247
32.LIU L., LI J., YUAN S., et. al., Evaluating the effectiveness of a preclinical practice of tooth preparation using digital training system: a randomised controlled trial, *Eur. J. Dent. Educ*. 2018;22(4): e679–e686
33.BUCHANAN J.A., Experience with Virtual Reality-Based Technology in Teaching Restorative Dental Procedures, *J. Dent. Educ*., 2004, 68(12):1258-1265
34.DIXON J., TOWERS A., MARTIN N., FIELD J., Re-defining the virtual reality dental simulator: Demonstrating concurrent validity of clinically relevant assessment and feedback., *Eur. J. Dent. Educ*., 2020, 28, 1-9.
35.SERRANO C.M., WESSELINK P.R., VERVOORN J.M., First experiences with patient-centered training in virtual reality, *J. Den.t Educ.* 2020;84(5):607-614.

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