2017-10

Computerized Virtual Reality Simulation in Preclinical Dentistry: Can a Computerized Simulator Replace the Conventional Phantom Heads and Human Instruction?

Plessas, A

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4 **TITLE PAGE**

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26 Word Count: 2.749

27 Conflict of interest: NONE

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34 **Summary Statement**

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36 In preclinical dental education, the acquisition of clinical, technical skills and the

37 transfer of these skills to the clinic are paramount. Phantom heads provide an

38 efficient way to teach preclinical students dental procedures safely while increasing

39 their dexterity skills considerably. Modern computerized phantom head training units

40 incorporate features of virtual reality technology and the ability to offer concurrent

41 augmented feedback. The aim of this review was to examine and evaluate the dental

42 literature for evidence supporting their use and discuss the role of augmented

43 feedback versus the facilitator's instruction. Adjunctive training in these units seems

44 to enhance student's learning and skill acquisition and reduce the required faculty

45 supervision time. However, the virtual augmented feedback cannot be used as the

46 sole method of feedback, and the facilitator's input is still critical. Well-powered

47 longitudinal randomized trials exploring the impact of these units on student's clinical

48 performance and issues of cost-effectiveness are warranted.

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50 147 words

51 Key Words: dental education, faculty, simulation training

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INTRODUCTION

Operative dentistry is a demanding area of clinical education [1]. The development of clinical competence requires the assimilation of large amounts of knowledge combined with the acquisition of clinical skills and problem-solving ability [1]. One of the most essential clinical skills in operative dentistry is preparing and restoring carious teeth. The student needs to comprehend the concepts of the procedure and develop the fine motor skills to perform it [2]. The acquisition of clinical, technical skills and the transfer of these skills to the clinic, where real patients are treated, is of paramount importance [3]. This can be achieved by vigorous training on phantom heads [4]. Phantom heads provide an efficient way to teach preclinical students dental procedures safely while increasing their psychomotor skills considerably [4, 5].

Phantom heads have been the cornerstone of learning in operative dentistry worldwide since their introduction in 1894 [4]. The phantom head is affixed to a dental operating unit with a torso, in a manner that allows adjustment of position to allow the students to work in a seated position as they would in a clinical setting [3]. The heads also have a rubber sheet which provides an approximation of the patient's cheeks and mouth opening (Figure 1) [3]. Phantom heads replicate the real-life clinical environment including positioning of the operator and the patient, performing dental procedures with an assistant, and infection control procedures[3]. Traditionally in preclinical simulation training, the students are shown models, diagrams, and pictures and are asked to repeatedly perform dental procedures on plastic phantom head teeth [6]. The learners receive verbal feedback by a

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77   faculty instructor when they have completed all or a portion of a cavity or

78   tooth preparation task (Figure 2) [7].

79   In recent years, technological advances have facilitated the incorporation of virtual

80   reality simulation technology in preclinical operative dental education. Virtual reality

81   simulators provide the opportunity for integrating clinical case scenarios in the

82   operative teaching environment and also facilitating the tactile diagnostic skills by

83   utilizing haptic technology [1]. To date, two types of computerized virtual reality dental

84   simulators are available: mannequin-based simulators on which certain dental

85   procedures can be performed using real dental instruments (e.g. DentSim TM and

86   Image Guided Implantology IGI both produced by the DenX, Ltd.) and haptic-based

87   simulators which employ a haptic device and virtual models of a human tooth or

88   mouth as a platform for facilitating the practise of dental procedures (e.g PHANToM

89   TM, Virtual Reality Dental Training System VRDTS, Iowa Dental Surgical Simulator,

90   HapTEL, VirDenT & Moog Simodont Dental Trainer) [1, 5, 6].

91   The mannequin-based computerized simulators combine the benefits of training on a

92   traditional phantom head operating unit [3], with the benefits of virtual reality simulation

93   [8]. These units were the focus of the present review; hereinafter referred to as CVRS.

94   A computerized phantom head dental simulator which incorporates virtual reality

95   features and provides augmented visual feedback is the DentSim Unit [1]. It has been

96   available since 1997 and has been used and evaluated in Dental Institutions in the

97   U.S., Europe, and Asia [1, 6, 9-11]. The unit includes a phantom head, a dental

98   handpiece, a light source, an infrared camera and two computers. The phantom

99   head and handpiece contain infrared emitters which allow the infrared camera to

100 detect their spatial orientation in space [6, 8]. As a student prepares a cavity in the

101 phantom head, the software formulates a virtual three-dimensional representation of

102 the preparation in progress which is presented on the computer screen (Figure 3) [6, 8].

103 The student's cavity preparation can be compared to the ideal cavity preparation by

104 overlaying the two virtual reality images at any time during the procedure [6, 8, 12].

105 Procedural errors are audio-signalled as they are made and the generated error

106 messages can be viewed immediately [12]. A final evaluation report and a list of errors

107 become available at the end of the procedure [6, 12]. The virtual environment is

108 enhanced with complete patient records including examination notes and

109 radiographs which provide a more realistic environment, bringing the technical tasks

110 into a clinical context, during the simulation training [12].

111 This aim of this review was to examine and evaluate the existing body of literature on

112 the use of the CVRS in preclinical dental education. The impact on student's

113 performance and learning experience, as well as the role of the faculty instruction

114 versus the augmented visual feedback provided by these units, in the clinical skills

115 acquisition simulation training, is discussed.

116 **METHODS**

117 A search of the literature was performed searching the following databases via

118 EBSCO: Medline, British Educational Index, and ERIC. The search terms used and

119 the search strategy can be found in Table 1. Papers in which the CVRS were

120 discussed in terms of preclinical dental education were included. Studies using

121 CVRS in postgraduate dental education as well studies using haptic technology

122 simulation systems were excluded. Only studies in the English language were

123 considered for inclusion. Finally, no limits for study design were applied.

124 The citations retrieved from the above search (79) were inserted into the reference

125 management software Endnote X7.4. The titles and abstracts were screened for

126 relevance. The potentially relevant papers (33) were accessed and read in full-text.

127 The selection process of the included studies (16) and the reasons for exclusion are

128 depicted in the PRISMA flowchart (Figure 4).

129 **RESULTS**

130 **Impact on student performance**

131 From the 79 articles retrieved, 16 were deemed relevant and were included in this

132 review. From these, five prospective experimental studies assessed the students'

133 performance in cavity preparation after additional training on the CVRS. The main

134 characteristics and results of these studies can be found in Table 2. Concerning the

135 quality of tooth preparations, most of the studies found no significant differences

136 between those who trained solely on conventional phantom heads versus those who

137 had been exposed adjunctively to the CVRS [2, 13-15]. Conversely, Kikuchi

138 demonstrated that students using the CVRS units performed better quality crown

139 preparations than those who did not [9]. Similarly, when first-year dental students

140 received eight hours of adjunctive computerized dental simulation training, although

141 they performed better early in the study, their clinical performance did not differ as

142 assessed by the final practical examination [12]. As the retention and transferability of

143 skill and knowledge are concerned, several studies found no significant differences

144 in final practical exam scores [12, 16, 17]. LeBlanc et al. did not identify any marked

145 differences in the final exam scores but observed a more significant improvement

146 between the first and final assessment scores for the CVRS group [2]. In contrast,

147 Magio et al. suggested that the introduction of the CVRS in preclinical dental training

148   resulted in a reduction in the course remediation rate and reduction of the course

149   failure rates by more than a half [18, 19].

150 **Time efficiency**

151   In an experimental study at the University of Pennsylvania, the students who

152   received CVRS training showed a higher efficiency in cavity preparations than the

153   students who trained on the traditional phantom heads [16]. Namely, they prepared

154   significantly more teeth per hour (3.8 versus 1.6) and used more teeth (average of

155   11.71 versus 6.57 for control, p=0.02) during their practising session [16]. Similarly,

156   training sessions with CVRS shortened the crown preparation time performed by

157   fifth-year dental students at Tokyo Medical and Dental University [9]. Besides, virtual

158   reality simulators appear to reduce the required instruction and supervision time by

159   faculty members of staff [16]. Jasinevicius et al. demonstrated that students who were

160   trained on conventional simulators received five times more instructional time from

161   faculty than students who were trained on virtual reality ones. However, there were

162   no statistically significant differences in the quality of the preparations despite the

163   additional instructional time [13].

164 **Student learning experience**

165   Several studies have surveyed dental students about their preferences over

166   conventional or virtual reality simulation. CVRS training seems to be rated rather

167   positively by the students. The majority (87.3%) of first-year students at Tennessee

168   Dental school working with CVRS found the experience to be ''very interesting'' or

169   ''interesting'' [11]. Amongst the positive features of virtual reality simulators, as

170   perceived by dental students, were the positive impact on improving their manual

171 and motor skills [16], the increased speed and number of preparations [10, 16], the access

172 to feedback [14], the ability for the student to monitor their own work without

173 involvement of a supervisor [10, 14], the preparation for assessment, the consistency of

174 evaluation [14, 15] and the allowance for self-paced learning [10, 14]. Students criticized

175 the CVRS for excessive feedback, lack of personal contact and technical difficulties

176 with hardware [14, 15]. Also, students agreed that virtual reality simulators could not

177 fully replace the conventional phantom heads and the combination of the two is the

178 most preferable and effective way of learning [14, 15]. On the other hand, students

179 found that the feedback and supervision by faculty facilitators can be inconsistent,

180 and supervisors can be too busy, but it increases their confidence in cavity

181 preparations [14, 15].

Feedback

183 As far as quality and effectiveness of instruction and feedback is concerned, several

184 studies have suggested that the virtual reality simulator could not be accepted as the

185 sole form of feedback and evaluation the students should be exposed to. Namely,

186 Urbankova et al. concluded that CVRS augmented feedback cannot replace human

187 instruction [12]. Quin et al. suggested that CVRS is not appropriate as a sole method of

188 feedback and evaluation for novice dental students [14, 15]. This statement agrees with

189 a later study in which sole CVRS feedback was not found beneficial, as the retention

190 and transfer test scores between students who used CVRS versus conventional

191 phantom heads did not differ significantly [17]. By the same token, Wierinck et al. have

192 suggested that alternating virtual reality with human instruction and feedback can

193 result in positive learning outcomes [7].

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DISCUSSION

The role of simulation has been recognized as an important aspect of training in healthcare which supports and improves patient safety [20]. Technology-enhanced simulation, including virtual reality training, has been associated with positive outcomes for healthcare trainee's knowledge and skills [21]. The use of virtual reality simulators for the training of novice surgical trainees has been supported by a number of systematic reviews [22-26]. In laparoscopic surgery, it has been shown to result in a significant reduction in operating time and procedural errors while improving the trainees' performance scores [23, 24]. Besides, two recent systematic reviews by the Cochrane Collaboration, in the fields of endoscopy and ENT surgery, suggested that virtual reality simulation can be used to supplement traditional surgical training for medical students and surgical trainees with little or no surgical experience [25, 26]. Nonetheless, the authors concluded that virtual reality training allows trainees to develop technical skills at least as good as those achieved through conventional training [25].

Similarly, adjunctive training on the dental CVRS has the potential to improve student's clinical performance and enhance their practical examination scores [9, 12, 15, 17]. The augmented feedback through visual cues can facilitate proper eye-hand coordination, and reduce the number of procedural errors [12]. Confronting the students with their own errors as they are made, allows them to visually inspect their work compared to an ideal model [14, 17] and instantaneously rectify it, which can potentially increase learning efficiency and skill development [12]. Noteworthily, although students seemed to perform better early after the CVRS training, their clinical performance in final exams did not differ from that of the students who trained

219 solely on traditional phantom-head units [12, 16, 17]. The fact that the amount of transfer

220 from one task onto another depends on the similarity of the neural processing

221 demands, underlying motor execution, may offer an explanation [17]. Besides, the

222 transferability of skills from one context to another is not an uncommon finding in

223 healthcare simulation. Namely, studies in the fields of bronchoscopy, endoscopy and

224 laparoscopic surgery have shown that skills acquired using virtual-reality simulation

225 will transfer to the operating room [27-29].

226 Nonetheless, with the expansion of the dental curricular content, the effective use of

227 student's time has become an increasing necessity [14]. CVRS training has shown to

228 improve students' efficiency in teeth preparations [9, 16] and reduce the required time

229 for faculty instruction and supervision [13]. Hence, the faculty instructors' time can be

230 utilized in teaching the students crucial non-procedural skills such as patient

231 management, ethics, and teamwork. Sharing their expertise and experiences in the

232 transition of a student from novice to clinician remains critical [7, 12].

233 The unsuitability of the use of CVRS feedback as the sole method of feedback and

234 evaluation for novice students is a consistent criticism amongst the included studies

235 [7, 14, 15, 17]. Although CVRS appear to be a reliable method for monitoring technical

236 progress, addressing the issue of lack of reproducibility amongst assessors [15]; they

237 cannot be used as a substitute for expert feedback. It has been suggested that the

238 extensively detailed and sometimes complex computer feedback can be

239 discouraging and overwhelming, especially for the inexperienced students [13, 17].

240 Appropriate faculty input will reinforce learned theoretical concepts and will provide

241 the students with insight into the weaknesses of their performance [2, 14]. Contextual

242 learning will enable the students to achieve a deeper understanding of theoretical

243 concepts and the impact of any procedural errors (e.g. the biological, clinical, and

244 medico-legal implications of damaging an adjacent tooth or unnecessarily preparing

245 a rather deep cavity).

246 In a modern preclinical environment, students will reflect on the feedback received

247 by the simulator, the facilitator or both. CVRS can provide the student with

248 continuous (100%) augmented feedback or they can be set to provide feedback less

249 frequently or none at all. In traditional phantom head preclinical courses, the

250 supervisors offer feedback at the end of critical parts of the procedure and the end of

251 the task. Usually, the ratio of supervisors to students does not permit every student

252 to receive constant feedback and instruction during the dental procedure. According

253 to Wierinck et al. continuous (100%) CVRS feedback during the task did not offer

254 any additional benefit over intermittent (66% of the time) feedback [7]. Nonetheless, a

255 recent meta-analysis suggested that terminal feedback appears more effective than

256 concurrent feedback for novice learners' skill retention [30]. The mechanism by which

257 feedback may be operating is in line with the guidance hypothesis [31] and to some

258 extent, the cognitive load theory [32].

259 The guidance hypothesis suggests that constant feedback from an instructor during

260 each practice attempt (concurrent feedback) may lead to an over-reliance on the

261 feedback such that when feedback is withdrawn, the learner's performance declines

262 [30, 31]. Reduced frequency of instruction may, therefore, enhance motor skill learning

263 and detection of errors [33]. According to the cognitive load theory, feedback provided

264 during a procedural skills session could influence cognitive load, either increasing it

265 by providing 'information-overload,' or decreasing it by structuring the task so that it

266   is better understood [30, 32]. Thus, it is plausible that continuous feedback may

267   cognitively overload the learner and hinder their learning [30].

268   The included studies assessed the suitability and effectiveness of the CVRS units as

269   an adjunctive training tool for novice dental students. These units can also act as a

270   valid and reliable screening device to capture expert performance [8]. Wierinck et.al

271   suggested that the DentSim unit can distinguish different levels of excellence in

272   performance (expert versus novice) [8]. On that ground, CVRS may be used in other

273   areas such as continuing dental education, continued competency of practitioners,

274   clinical board exams and remediation of impaired practitioners [6]. Future research will

275   be needed to explore the feasibility of CVRS in these areas. Furthermore, evidence

276   for the long-term effect of CVRS training on the students' clinical performance and

277   competence as well as data regarding the cost-effectiveness of these devices is

278   currently lacking. Future studies should conform to the extended CONSORT and

279   STROBE reporting guidelines for healthcare simulation research[20], to ensure

280   complete reporting and transparency in the research conduct [20, 34].

281   **CONCLUSION**

282   The existing body of evidence suggests that combining and alternating the traditional

283   and pioneering simulation methods and feedback may be of benefit to the learners.

284   However, there is insufficient evidence to advise for or against the use of

285   computerized virtual reality simulators as a replacement of the traditional phantom

286   heads and human instruction. Virtual reality simulation may enable a better

287   understanding among learners in a more diverse learning environment and augment

288   rather than replace existing teaching methods that work well such as faculty

289   instruction and feedback. Incorporating such a technology in the dental curriculum

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290 can add a substantial expense nevertheless to a dental faculty's budget. Well-

291 designed and adequately powered long-term prospective studies exploring matters

292 of student performance, learning outcomes, and cost effectiveness are warranted.

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294 **ACKNOWLEDGMENTS**

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416 **Table and Figure Legends**

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418 Table 1: Search strategy

419 Table 2: Studies comparing student's performance (CVRS versus traditional
420   phantom heads)

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Figure Legends

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Figure 1. Phantom head dental simulator unit. Image courtesy of Plymouth University, Peninsula School of Medicine and Dentistry.

Figure 2. Traditional dental simulation training and faculty instruction. Images courtesy of Plymouth University Peninsula School of Medicine and Dentistry.

Figure 3. CVRS training interface for cavity preparation (DentSim^{TM}). Images courtesy of Professor Els Wierinck, KU Leuven - Department of Oral Health Sciences, University Hospitals Leuven, Belgium.

Figure 4. Flowchart. Study selection process.

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