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

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TITLE PAGE

Title: Computerized Virtual Reality Simulation in Preclinical Dentistry.
Can a computerized simulator replace the conventional phantom heads and human instruction?

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Summary Statement

In preclinical dental education, the acquisition of clinical, technical skills and the transfer of these skills to the clinic are paramount. Phantom heads provide an efficient way to teach preclinical students dental procedures safely while increasing their dexterity skills considerably. Modern computerized phantom head training units incorporate features of virtual reality technology and the ability to offer concurrent augmented feedback. The aim of this review was to examine and evaluate the dental literature for evidence supporting their use and discuss the role of augmented feedback versus the facilitator’s instruction. Adjunctive training in these units seems to enhance student’s learning and skill acquisition and reduce the required faculty supervision time. However, the virtual augmented feedback cannot be used as the sole method of feedback, and the facilitator’s input is still critical. Well-powered longitudinal randomized trials exploring the impact of these units on student’s clinical performance and issues of cost-effectiveness are warranted.

147 words

Key Words: dental education, faculty, simulation training

53

54 **INTRODUCTION**

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

65 Phantom heads have been the cornerstone of learning in operative dentistry
66 worldwide since their introduction in 1894 ⁴. The phantom head is affixed to
67 a dental operating unit with a torso, in a manner that allows adjustment of
68 position to allow the students to work in a seated position as they would in a
69 clinical setting ³. The heads also have a rubber sheet which provides an
70 approximation of the patient's cheeks and mouth opening (Figure 1) ³.
71 Phantom heads replicate the real-life clinical environment including
72 positioning of the operator and the patient, performing dental procedures
73 with an assistant, and infection control procedures³. Traditionally in
74 preclinical simulation training, the students are shown models, diagrams,
75 and pictures and are asked to repeatedly perform dental procedures on
76 plastic phantom head teeth ⁶. The learners receive verbal feedback by a

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 technology¹. 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 unit³, with the benefits of virtual reality simulation
93⁸. 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 Unit¹. 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}.

182 **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.

194

195 **DISCUSSION**

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

210 Similarly, adjunctive training on the dental CVRS has the potential to improve
211 student's clinical performance and enhance their practical examination scores ^{9, 12, 15,}
212 ¹⁷. The augmented feedback through visual cues can facilitate proper eye-hand
213 coordination, and reduce the number of procedural errors ¹². Confronting the
214 students with their own errors as they are made, allows them to visually inspect their
215 work compared to an ideal model ^{14, 17} and instantaneously rectify it, which can
216 potentially increase learning efficiency and skill development ¹². Noteworthy,
217 although students seemed to perform better early after the CVRS training, their
218 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 explanation¹⁷. 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 room²⁷⁻²⁹.

226 Nonetheless, with the expansion of the dental curricular content, the effective use of
227 student's time has become an increasing necessity¹⁴. CVRS training has shown to
228 improve students' efficiency in teeth preparations^{9, 16} and reduce the required time
229 for faculty instruction and supervision¹³. 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 assessors¹⁵; 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 research²⁰, 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

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.

293

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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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444 **Figure Legends**

445

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

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

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

453 Figure 4. Flowchart. Study selection process.

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