Research article

Efficacy of CAD/CAM technology in dental procedures performed by students: A systematic scoping review of randomized clinical trials

Carlos M. Ardila [a],[*], Daniel González-Arroyave [b]

[a] *Basic Studies Department, Faculty of Dentistry, University of Antioquia, UdeA, 050010 Medellín, Colombia*
[b] *Medicine Department, San Vicente Fundación Hospital, 054047 Rionegro, Colombia*

ARTICLE INFO

ABSTRACT

Objectives: To assess the efficacy of computer-aided design/computer-aided manufacturing (CAD/CAM) in dental procedures performed by dental students. Methods: A systematic scoping review was performed. MeSH terms and keywords were specified to assess randomized clinical trials (RCTs) in all idioms. Results: Nine RCTs that include 520 students were selected. Two RCTs studied implant placement, and the rest of the trials explored implant impressions, intraoral scans, canal obturation, head positioning errors in panoramic images, deep caries and pulp exposure, diagnosis of temporomandibular disorders, and a tooth for restorations. Considering efficacy, variable results were found. The RCTs that explored implant impressions, deep caries and pulp exposure, and diagnosis of temporomandibular disorders showed better results when CAD/CAM technology was performed by students. Two RCTs that investigated implant placement presented contradictory outcomes; one showed better results when CAD/CAM systems were used while the other described similar results to conventional methods. The remaining RCTs did not find differences with conventional procedures. Considering the time spent during the procedures, two studies showed no differences between groups, while another indicated that the time spent was less for digital impressions ($p < 0.001$). A continuous decrease in scanning time was also perceived for all groups as skills in intraoral scanning augmented ($p = 0.0005$). Students indicated an interest in utilizing the CAD/CAM systems and recognized that their abilities were enhanced. Conclusions: Considering the limitations of this review and the limited number of RCTs evaluated, students recognized that their skills improved using CAD/CAM systems; however, only in some specific procedures greater efficacy and less time spent were observed when this technology was used. Dental students also showed great interest in using these techniques.

1. Introduction

The introduction of computer-aided design/computer-aided manufacturing (CAD/CAM) knowledge has caused much novelty to odontology. In dentistry, this equipment has been included throughout diagnosis and therapies procedures. CAD/CAM expertise assists a completely digital plan; furthermore, some protocol reports have proposed clinical consistency, and it has been denoted that this equipment makes very advantageous response from patients [1,2]. A retrospective investigation also recommended that CAD/CAM

---

functions diminished management time [3].

Digital technology has been successfully adopted in many areas of dentistry. It is used, for example, in computer-aided impression-taking, in the fabrication of restorations at the chairside and the dental laboratory, for digital tooth shade determination, and in various formats of digital imaging, including intraoral dental radiographs, panoramic tomography, and cone-beam computed tomography [4–6].

Digital possibilities also involve learning in dentistry. Dental programs necessity to be digitally updated and must incorporate dental procedures with virtual technologies and software interpretations [7]. Currently, dental undergraduates diverge from their previous peers in that they are, as participants of a digitally intermediated generation, recognizable with the knowledge of simulation virtual experience. The students habitually implement computerized devices in a virtual scenery [8], which is why it is usually expected that dental undergraduates will consent and even select digital strategies [9]. Furthermore, virtually all universities are examining for more competent forms to instruct learners, incorporating digital skills [10].

Dental institutions have also described the outcomes of operating several tools in the training of their undergraduates [10]. Consequently, it has been settled that its efficiency is related to time, effectiveness, and faculty understanding of dental student implementation [11,12].

Evaluating the preeminent obtainable scientific evidence across randomized clinical trials (RCTs) that contrast CAD/CAM tools with standard treatments in dental procedures performed by students, will permit dental schools to construct improved decisions to implement these technologies in their programs. Therefore, it is relevant to perform a systematic scoping review of RCTs, which permits for assessing the efficacy of CAD/CAM equipment in procedures performed by students. It is important to highlight that the scoping reviews seek to fill the gaps in the literature. To complete this aim, it was planned to respond selected interrogations linked to the efficacy, time spent, and perceptions of utilizing CAD/CAM systems by dental students.

2. Methods

Considering that scoping reviews aid the planning and commissioning of future research, this systematic scoping review of RCTs was performed seeing the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) extension for this kind of studies [13]. The scoping format incuded diverse resources such as PubMed, SCOPUS, LILACS and SCIELO, incorporating the gray literature. MeSH terms and keywords permitted to assess RCTs performed on dental students in all languages before January 2023 containing computer-aided design, 3D management development, CAD/CAM technique, dental students, dental education, experimental investigations, and randomized clinical trials. Then, a process was implemented to research databases, utilizing Boolean operators (AND, OR): "computer-aided design" OR "3D models" OR "CAD/CAM systems" AND "3D treatment planning" AND "dental students" OR "dental education" AND "intervention studies" OR "randomized clinical trial".

2.1. Selection criteria

Inclusion criteria: Only RCTs evaluating the efficacy of CAD/CAM technology in undergraduate dental students were included.

Exclusion criteria: Research related to the efficacy of teaching using CAD/CAM, students' cognitive field, observational studies, case studies, duplicate investigations, in vitro trials, and animal reports were discarded.

2.2. Interrogations

The following questions were considered: Do procedures with CAD/CAM technology performed by dental students show higher efficacy than conventional methodology? Do procedures with CAD/CAM technology performed by dental students require less time? Which is the perception of dental students when they use CAD/CAM systems?

2.3. Examination procedure

Both researchers (CMA and DAG) revised the titles and abstracts and designated RCTs to evaluate the article for possible suitability. This process was done manually. In case of divergence among researchers, RCT suitability was considered by agreement. The Kappa analysis was utilized to measure the rate of consensus among authors (>95), using IBM SPSS Statistics 22.

2.4. Information compilation

A tool was proposed to integrate the most pertinent information from the chosen RCTs. This activity was implemented individually by each of the investigators. Successively, the information was contrasted. Documented records involved investigators' surnames, year of publication, demographic information of the students, number of students, CAD/CAM procedures, and control, comparison between the groups (principal reviewed variables), time spent during the procedure, and perceptions of dental students about CAD/CAM systems.

2.4.1. Critical appraisal

Critical appraisal and quality valuation of the studied RCTs was accomplished using a recognized scale for RCTs [14], by both researchers.

3. Results

The initial online exploration generated 263 reports of which 209 were excluded because they were not RCTs. After reviewing the titles and abstracts, 37 investigations were excluded. Considering the full text caused the rejection of 8 additional studies. Ultimately, 9 RCTs [4,9,10,15–21] were studied here (Fig. 1). One RCT was reported in two publications with different outcomes [15,16].

Table 1 depicts the features of the studied RCTs. These trials were available among 2014 and 2022. These studies evaluated 520 students with samples between 6 [18] and 145 students [17]. The trials studied here estimated procedures performed by students in different areas of dentistry.

Two RCTs studied implants placement [18,20], and the rest of the trials explored implant impressions [9], intraoral scans [15,16], canals obturation [17], head positioning errors in panoramic images [19], deep caries and pulp exposure [21], diagnoses of temporomandibular disorders [4], and a tooth for restorations [14].

Regarding the efficacy of procedures with CAD/CAM technology performed by dental students, variable results were found in this review. The RCTs that studied intraoral scans [15,16], canal obturation [17], head positioning errors in panoramic images [19], and a tooth for restorations [10] did not find differences with conventional procedures. The RCTs that explored implant impressions [7], deep caries and pulp exposure [21], and diagnosis of temporomandibular disorders [4] showed better results when CAD/CAM technology was performed. Finally, two RCTs that investigated implant placement presented contradictory outcomes; one showed better results when CAD/CAM systems were used [18] while the other described similar results to conventional methods [20]. However, Søndergaard et al. [20] described that facio-lingual angular deviation and apical deviation were lower when a fully guided protocol placement was used.

Seeing the time spent through the procedures performed by dental students, the outcomes were likewise variable. Two studies showed no differences between groups [10,20], while Zitzmann et al. [9] indicated that the complete outcomes for the mean entire performance time of all stages were 301.3 s (±105.9; 153–650 range) for digital impressions in a harmonized phantom prototype (IOS), and 722.7 s (±120.2; 467–1030) for standard impressions (P < 0.001). On the other hand, Waldecker et al. [16] documented that a constant diminution in scanning time was perceived for all groups as skill in intraoral scanning augmented (P = 0.0005). The rest of the RCTs did not report anything about time spent.

Concerning the third interrogation, it was found that in the study of Zhang et al. [18] most undergraduates contemplated their performance to have been augmented by repeating the practice in either the conventional instruction group or the dynamical navigation group. Zitsmann et al. [9] found that most of the apprentices observed IOS as more accessible than the standard practice. The majority (72%) chose the digital methodology implementing intraoral optical scanning to take the implant impression to the standard technique (12%) or had no predilection (12%). Søndergaard et al. [20] informed that various scholars faced that the learning product when applying the fully guided procedure was diminished, as they did not "think for themselves" when effecting the procedure. Finally, in one RCT, students indicated an interest in utilizing CAD/CAM technology [10], while greater confidence and knowledge gained were observed in one study [21]. The other RCTs revised here did not report students' perceptions.
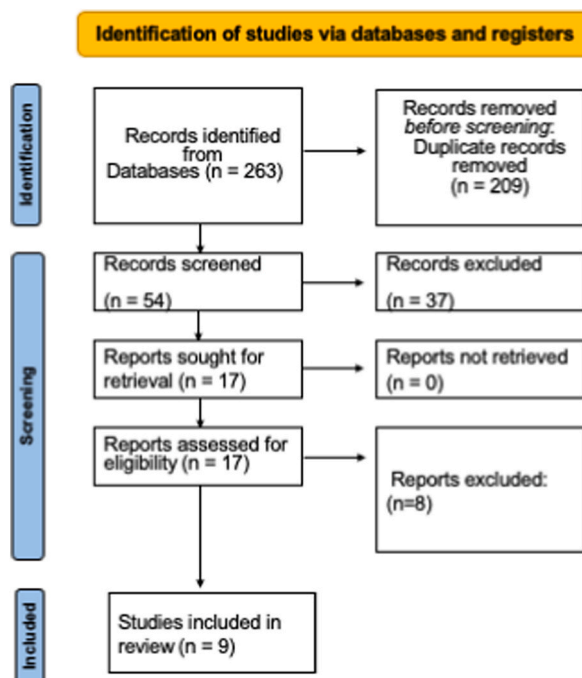

Fig. 1. Flowchart of the randomized clinical trials selection method.

Table 1

Characteristics of the randomized clinical trials (RCTs) assessed.

Researchers	Students	Mean Age	Female Male	Intervention. Control	Main Outcomes	Time spent	Students Perceptions
Chevalier et al., 2022 [21]	108	21 years	71/37	This study compared a vital pulp treatment (VPT) lecture- only (control) group and a VPT- lecture combined with a VPT-laboratory (experimental) group.	More confidence and knowledge gained in the experimental group (P < 0.05).	Not reported	The majority of scholars described that they liked the session and considered it convenient as a replication of caries removal and was principally valuable for deep caries removal.
Waldecker et al., 2021 [15, 16]	36	Not reported	Not reported	This randomized clinical trial (RCT) evaluated the effect of training on scanning times and scanning exactitude of complete-arch scans (CAS), with a distinction made between specific training (repeated practice of CAS) versus nonspecific training.	Repeated CAS resulted in improved scanning accuracy in both groups (P > 0.05).	A continual decrease in scanning time was observed for all groups as experience in intraoral scanning increased (P = 0.0005).	Not reported
Peters et al., 2021 [17]	145	Not reported	Not reported	An experimental group obturated canals of a 3D-printed tooth versus a control group that did not obturate the tooth model but received identical instruction. Later in the course, all students obturated an extracted human mandibular molar tooth.	Dental students' obturation skills did not significantly improve by further practicing obturation using a 3D-printed model.	Not reported	Not reported
Zhang et al. 2020 [18]	6	Not reported	Not reported	Dental students with no implant placement experience were randomly assigned to implant placement training using a dynamic navigation system or a traditional freehand protocol.	Students showed significantly greater improvement in implant placement after training using the dynamic navigation system than after using the traditional freehand protocol. Overall deviation of the implant axis (P < 0.001) and 3D apex deviation (P = 0.014) improved with training using the dynamic navigation system.	Not reported	Most participants in this study considered their execution to have improved by repeating the assignment in either the traditional training group or the dynamic navigation group.
Wenzel et al., 2020 [19]	60	23 years	47/13	Ability to recognize head positioning errors in panoramic (PAN) images after individual learning via computer-assisted-learning (CAL) and in a simulation clinic (SIM). A control group (CON) without training was also included. Performance in the patient examination was assessed.	All students performed well in the sagittal plane. Students in the SIM group positioned the patient more correctly in the coronal plane (P < 0.01)	Not reported	Not reported
Sondergaard et al. 2020 [20]	Not reported	Not reported	Not reported	To compare fully guided (FG) with conventionally guided (CG) implant surgery performed in terms of the deviation of actual implant position from an	It was reported no difference in 5 out of 7 deviational parameters concerning the actual implant position	The mean time spent was similar for both groups.	Some students felt that the learning outcome when using the fully guided procedure was diminished, as they

Table 1 (*continued*)

Researchers	Students	Mean Age	Female Male	Intervention. Control	Main Outcomes	Time spent	Students Perceptions
				ideal implant position. Each surgery was performed as a collaboration between two final-year dental students supervised by a maxillofacial surgeon. Twenty-five patients in need of 26 straightforward implant- supported single crowns were randomly allocated to a fully guided (FG, n = 14) or a conventionally guided (CG, n = 12) implant surgery.	regarding the ideal implant position between an FG and CG implant. Facio-lingual angular deviation and apical deviation were lower when an FG protocol placement protocol was used.		did not have to "think for themselves" when performing the surgery.
Becker et al. 2018 [4]	39	Not reported	Not reported	To study whether computer-aided diagnosis (CADx) of temporomandibular disorders (TMD) offers quality advantages over traditional diagnosis (TRAD).	Median agreement with the reference diagnoses was significantly higher (P < 0.001) with computer assistance than without it. Median interexaminer consistency of diagnoses was significantly higher (P < 0.001) with computer assistance than with traditional diagnostic methods alone. Likewise, the number of false-positive and false-negative diagnoses was significantly lower with computer assistance.	Not reported	Not reported
Zitsmann et al., 2017 [9]	50	24 years	27/23	Group A first took digital impressions in a standardized phantom model and then conventional impressions, while the procedures were reversed for Group B.	Dental students' performance was similar for both groups.	The overall results for the mean total work time of all steps were 301.3 s (±105.9; 153–650 range) for digital impressions in a standardized phantom model (IOS) and 722.7 s (±120.2; 467–1030) for conventional impressions (p < 0.001).	Most students perceived IOS as easier than the conventional technique. Most (72%) preferred the digital approach using intraoral optical scanning to take the implant impression to the conventional method (12%) or had no preference (12%).
Callan et al., 2014 [10]	76	26 years	34/42	CAD/CAM technology on preparing a tooth for restoration versus traditional preparation methods	The effectiveness analysis showed no difference in outcomes by intervention group assignment. There were higher mean competency exam scores for students reporting the use of CAD/CAM compared to those who did not use the technology, but these results did not reach statistical significance.	No differences regarding time spent were observed between groups.	Students indicated an interest in utilizing the technology.

Critical appraisal and quality assessment of the included RCTs indicated that two trials presented a high risk of bias [15,17] while the others presented a moderate risk of bias (Table 2).

4. Discussion

This systematic scoping review is the first to compare the efficacy of CAD/CAM equipment with usual treatments in procedures performed by dental students. Seeing that the novel CAD/CAM knowledges recommend innovations linked to clinical procedures implemented in dentistry, an aspect that can innovate curricula in dental schools, it is indispensable to estimate their clinical efficacy with the finest presented scientific evidence. Considering these aspects, responses were specified to each of the three planned questions of this review.

Concerning the efficacy of procedures with CAD/CAM technology performed by dental students, variable results were found in this review. Some RCTs [10,15–17,19,20] did not find differences with conventional procedures, while other studies did [4,7,18,21]. In this regard, it has been indicated that the potential for improvement using CAD/CAM systems depends on the skill of the user [15,22]; less trained clinicians are less skilled than competent doctors at reacting to patient motion, saliva, and soft tissues in combination with CAD/CAM technologies [23]. Moreover, despite enhancements in CAD/CAD systems, it appears that new procedures and practices are being seen with more resistance by clinicians and dental faculty [16]. Other comparative investigations documented minus dramatic outcomes implementing other computer-assisted procedures; however, each observed optimistically the potential of those technologies [24–26]. In this manner, it is observed that in terms of efficacy, only some clinical procedures performed with CAD/CAM technology by dental students present better results, in such a way that there is still a gap in knowledge that requires the performance of more clinical trials, especially in the areas where findings are more controversial.

Considering the time spent during the procedures performed by dental students, the results were also variable in this review. Similarly, other comparative studies also show contradictory results. One research by a second-year undergraduate needed less time to note the digital procedure concerned in taking an impression and designing a ceramic crown than they required for a standard wax pattern of a full-contour crown [27]. A clinical study also indicated that chairside CAD/CAM dentistry diminished chairside time [28], while a recent retrospective study informed that their results provide support for the additional time of CAD/CAM technologies [29]. Similar results were also reported in medical students [30,38]. As was found in terms of efficacy in this review, the results related to the optimization of time during the use of CAD/CAM technologies are also controversial. Thus, in this case, more studies are also required to elucidate this problem.

This review found that, in general terms, dental students were interested in learning about the new CAD/CAM systems. In this regard, it has been informed that the students read less and be more attracted to CAD/CAM technologies [31]. This is how different programs have incorporated these technologies into their curricula [32,33]. In this aspect, this systematic scoping review is very conclusive because most of the students reported great interest and comfort when they used this type of technology.

As a supplementary value in this review, it was documented a notable diminution in laboratory expenses across the utilization of CAD/CAM technologies in the student clinics [26]. However, a clinical trial indicated that the costs of CAD/CAM technology are slightly higher than those of an orthodontist using conventional treatments [33]. Penning et al. [34] indicated this is because CAD/CAM technology is more expensive due to laboratory costs. The costs of CAD/CAM technology present controversial results in other specialties of dentistry. Some studies indicate that the costs are like conventional treatments, while others indicate that the values are lower [35,36]. More cost-effectiveness studies are required when using CAD/CAM systems in dentistry to present more conclusive results in this regard.

The principal weakness of this systematic scoping review is associated to the small number of included studies, which unfortunately makes it difficult to present more robust conclusions. Moreover, two RCTs selected presented a high risk of bias [16,17]. These biases were linked mainly to double-blinding [4,9,10,15–18,21]. It was described that blinding the interventions is difficult when CAD/CAM systems are used [37]. Nevertheless, a superior amount of RCTs with a low risk of bias are needed to permit more irrefutable outcomes.

5. Conclusions

Undergraduates admitted that their abilities improved implementing CAD/CAM techniques; nevertheless, just in certain procedures, such as implant impressions, diagnosis of temporomandibular disorders, deep caries and pulp exposure, and implant placement,

Table 2
Critical appraisal and quality of the studied trials [14].

Randomized clinical trial	Randomization	Double Blinding	Withdraw	Appropriate randomization	Appropriate double blinding	Total
Chevalier et al., 2022 [21]	1	0	1	1	0	3
Waldecker et al., 2021 [15,16]	1	0	1	0	0	2
Peters et al., 2021 [17]	1	0	1	0	0	2
Zhang et al., 2020 [18]	1	0	1	1	0	3
Wenzel et al., 2020 [19]	1	1	1	1	0	4
Sondergaard et al., 2020 [20]	1	1	1	1	0	4
Becker et al., 2018 [4]	1	0	1	1	0	3
Zitsmann et al., 2017 [9]	1	0	1	1	0	3
Callan et al., 2014 [10]	1	0	1	1	0	3

greater efficacy was observed when this technology was used. Similarly, less time spent was perceived when digital impressions and scanning were performed with CAD/CAM systems. However, in this systematic scoping review clear conclusions could not be conducted due to the low number of included studies; therefore, further research is needed.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Declaration of competing interest

The authors declare that they have no competing interests.

Additional information

None.

Author contribution statement

Carlos M. Ardila and Daniel González-Arroyave: conceived and designed the experiments; performed the experiments; Analyzed and interpreted the data; wrote the paper.

Data availability statement

The datasets used and/or analyzed during the present study are available from the corresponding author upon reasonable request.

Declaration of interest's statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] M.F. Sfondrini, P. Gandini, M. Malfatto, F. Di Corato, F. Trovati, A. Scribante, Computerized casts for orthodontic purpose using powder-free intraoral scanners: accuracy, execution time, and patient feedback, BioMed Res. Int. 4103232 (2018).
[2] C. Xue, H. Xu, Y. Guo, et al., Accurate bracket placement using a computer-aided design and computer-aided manufacturing-guided bonding device: an in vivo study, Am. J. Orthod. Dentofacial Orthop. 157 (2020) 269–277.
[3] M.W. Brown, L. Koroluk, C.C. Ko, K. Zhang, M. Chen, T. Nguyen, Effectiveness and efficiency of a CAD/CAM orthodontic bracket system, Am. J. Orthod. Dentofacial Orthop. 148 (2015) 1067–1074.
[4] K. Becker, H.A. Jakstat, M.O. Ahlers, Quality improvement of functional diagnostics in dentistry through computer-aided diagnosis: a randomized controlled trial, Int. J. Comput. Dent. 21 (2018) 281–294.
[5] M. Zimmermann, A. Mehl, W.H. Mörmann, S. Reich, Intraoral scanning systems - a current overview, Int. J. Comput. Dent. 18 (2015) 101–129.
[6] M. Zaruba, A. Mehl, Chairside systems: a current review, Int. J. Comput. Dent. 20 (2017) 123–149.
[7] N. Mattheos, D. Wismeijer, L. Shapira, Implant dentistry in postgraduate university education. Present conditions, potential, limitations and future trends, Eur. J. Dent. Educ. 18 (2014) 24–32.
[8] C. Marinello, The digital revolution in prosthodontics: can it benefit older people? Gerodontology 33 (2016) 145–146.
[9] N.U. Zitzmann, I. Kovaltschuk, P. Lenherr, P. Dedem, T. Joda, Dental students' perceptions of digital and conventional impression techniques: a randomized controlled trial, J. Dent. Educ. 81 (2017) 1227–1232.
[10] R.S. Callan, C.L. Palladino, A.R. Furness, E.L. Bundy, B.L. Ange, Effectiveness and feasibility of utilizing E4D technology as a teaching tool in a preclinical dental education environment, J. Dent. Educ. 78 (2014) 1416–1423.
[11] R. Gottlieb, S.K. Lanning, J.C. Gunsolley, J.A. Buchanan, Faculty impressions of dental students' performance with and without virtual reality simulation, J. Dent. Educ. 75 (2011) 1443–1451.
[12] J.A. Buchanan, Experience with virtual reality-based technology in teaching restorative dental procedures, J. Dent. Educ. 68 (2004) 1258–1265.
[13] A.C. Tricco, E. Lillie, W. Zarin, K.K. O'Brien, H. Colquhoun, D. Levac, et al., PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation, Ann. Intern. Med. 169 (2018) 467–473.

[14] A.R. Jadad, R.A. Moore, D. Carroll, C. Jenkinson, D.J. Reynolds, D.J. Gavaghan, et al., Assessing the quality of reports of randomized clinical trials: is blinding necessary? Contr. Clin. Trials 17 (1996) 1–12.

[15] M. Waldecker, S. Rues, C. Trebing, R. Behnisch, P. Rammelsberg, W. Bömicke, Effects of training on the execution of complete-arch scans. Part 1: scanning time, Int. J. Prosthodont. (IJP) 34 (2021) 21–26.

[16] M. Waldecker, S. Rues, C. Trebing, R. Behnisch, P. Rammelsberg, W. Bömicke, Effects of training on the execution of complete-arch scans. Part 2: scanning accuracy, Int. J. Prosthodont. (IJP) 34 (2021) 27–36.

[17] O. Peters, R. Scott, A. Arias, E. Lim, F. Paque, S. Almassi, et al., Evaluation of dental students' skills acquisition in endodontics using a 3D printed tooth model, Eur Endod J 6 (2021) 290–294.

[18] Y. Zhan, M. Wang, X. Cheng, Y. Li, X. Shi, F. Liu, Evaluation of a dynamic navigation system for training students in dental implant placement, J. Dent. Educ. 85 (2021) 120–127.

[19] A. Wenzel, L.H. Matzen, R. Spin-Neto, L. Schropp, Effect of computer-assisted-learning and simulation clinics on dental students' cognitive and performance skills: panoramic image errors related to patient's head position, Dentomaxillofacial Radiol. 49 (2020), 20200154.

[20] K. Søndergaard, M. Hosseini, S. Storgård Jensen, R. Spin-Neto, K. Gotfredsen, Fully versus conventionally guided implant placement by dental students: a randomized controlled trial, Clin. Oral Implants Res. 32 (2021) 1072–1084.

[21] V. Chevalier, M. Dessert, K.J. Fouillen, S. Lennon, H.F. Duncan, Preclinical 3D-printed laboratory simulation of deep caries and the exposed pulp reduced student anxiety and stress, while increasing confidence and knowledge in vital pulp treatment, Int. Endod. J. 55 (2022) 844–857.

[22] J.H. Lim, J.M. Park, M. Kim, S.J. Heo, J.Y. Myung, Comparison of digital intraoral scanner reproducibility and image trueness considering repetitive experience, J. Prosthet. Dent 119 (2018) 225–232.

[23] P. Ahlholm, K. Sipilä, P. Vallittu, M. Jakonen, U. Kotiranta, Digital versus conventional impressions in fixed prosthodontics: a review, J. Prosthodont. 27 (2018) 35–41.

[24] C.C. Gadbury-Amyot, J.H. Purk, B.J. Williams, C.J. Van Ness, Using tablet technology and instructional videos to enhance preclinical dental laboratory learning, J. Dent. Educ. 78 (2014) 250–258.

[25] W.G. Renne, S.T. McGill, A.S. Mennito, B.J. Wolf, N.M. Marlow, S. Shaftman, et al., E4D compare software: an alternative to faculty grading in dental education, J. Dent. Educ. 77 (2013) 168–175.

[26] W.D. Browning, P. Reifeis, L. Willis, M.L. Kirkup, Including CAD/CAM dentistry in a dental school curriculum, J. Indiana Dent. Assoc. 92 (2013) 40–47.

[27] R.D. Douglas, C.D. Hopp, M.A. Augustin, Dental students' preferences and performance in crown design: conventional wax-added versus CAD, J. Dent. Educ. 78 (2014) 1663–1672.

[28] C. Batisse, P.Y. Cousson, E. Nicolas, M. Bessadet, Aesthetic and functional rehabilitation of patients with genetic microdontia: a multidisciplinary approach, Health Care 10 (2022) 485.

[29] E.B. Rosen, R. Kyle Gazdeck, D.A. Goldman, H. Panchal, E. Jones, J.P. Nguyen, et al., An anatomic analysis of fibula flap mandible reconstructions: implications for endosseous implant placement, Plast. Reconstr. Surg. 10 (2022) 1097.

[30] C.M. Ardila, D. González-Arroyave, M. Zuluaga-Gómez, Efficacy of three-dimensional models for medical education: a systematic scoping review of randomized clinical trials, Heliyon 9 (2023) e13395.

[31] F.S. Schwindling, U.K. Deisenhofer, M. Porsche, et al., Establishing CAD/CAM in preclinical dental education: evaluation of a hands-on module, J. Dent. Educ. 79 (2015) 1215–1221.

[32] P.E. Reifeis, M.L. Kirkup, L.H. Willis, W.D. Browning, Introducing CAD/CAM into a predoctoral dental curriculum: a case study, J. Dent. Educ. 78 (2014) 1432–1441.

[33] I. Czolgosz, P.M. Cattaneo, M.A. Cornelis, Computer-aided indirect bonding versus traditional direct bonding of orthodontic brackets: bonding time, immediate bonding failures, and cost-minimization. A randomized controlled trial, Eur. J. Orthod. 43 (2021) 144–151.

[34] E.W. Penning, R.H.J. Peerlings, J.D.M. Govers, R.J. Rischen, K. Zinad, E.M. Bronkhorst, et al., Orthodontics with customized versus noncustomized appliances: a randomized controlled clinical trial, J. Dent. Res. 96 (2017) 1498–1504.

[35] S. Mühlemann, J. Hjerppe, C.H.F. Hämmerle, D.S. Thoma, Production time, effectiveness and costs of additive and subtractive computer-aided manufacturing (CAM) of implant prostheses: a systematic review, Clin. Oral Implants Res. 32 (2021) 289–302.

[36] M. Srinivasan, P. Kamnoedboon, G. McKenna, L. Angst, M. Schimmel, M. Özcan, et al., CAD-CAM removable complete dentures: a systematic review and meta-analysis of trueness of fit, biocompatibility, mechanical properties, surface characteristics, color stability, time-cost analysis, clinical and patient-reported outcomes, J. Dent. 113 (2021), 103777.

[37] J. Hegele, L. Seitz, C. Claussen, U. Baumert, H. Sabbagh, A. Wichelhaus, Clinical effects with customized brackets and CAD/CAM technology: a prospective controlled study, Prog. Orthod. 22 (2021) 40.

[38] T. Koulopoulos, D. Keldsen. The Gen Z effect, Bibliomotion, Brookline, MA, 2014.