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CAD/CAM Education Experience and Utilization Competency of Dental Hygiene and Dental Technology Students: A Comparative Study

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Abstract

Background: The use of computer-aided design and manufacturing (CAD/CAM) technology is rapidly expanding in modern dentistry. However, differences may exist in educational experiences and utilization competencies between dental hygiene and dental technology students. **Objectives:** This study aimed to assess CAD/CAM educational exposure and competencies by major and grade level. **Methods:** A cross-sectional online survey was conducted with 464 undergraduate students in Korea. The questionnaire covered general characteristics, CAD/CAM education experience, and competencies in scanning, CAD design, CAM operation, and post-processing. Data were analyzed using descriptive statistics, independent-samples *t*-tests, and correlation analysis. **Results:** A total of 464 valid responses were analyzed. Dental technology students reported significantly higher experience with CAD/CAM education compared with dental hygiene students ($p < 0.001$). Scanning, CAD design, CAM operation, and post-processing competency were all significantly higher among dental technology students and senior (3–4 year) students compared with dental hygiene and junior (1–2 year) students ($p < 0.001$). CAD/CAM competencies varied significantly by major and grade level. **Conclusions:** These findings emphasize the need to strengthen CAD/CAM training in dentistry curricula and to promote interdisciplinary digital dentistry education to prepare practice-ready graduates for a digitized clinical environment.

Keywords: CAD/CAM; digital dentistry; dental hygiene; dental technology; education

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1. Introduction

Dentistry has undergone a rapid digital transformation, with technologies such as computer-aided design/computer-aided manufacturing (CAD/CAM) significantly enhancing conventional workflows and improving efficiency, accuracy, and clinical outcomes [1,2]. CAD/CAM systems enable the digital design and fabrication of dental prostheses, reducing errors and chairside time compared with conventional techniques while ensuring high precision [1,3]. Consequently, CAD/CAM has become an essential component of contemporary dental practice, ranging from chairside restorations to efficient laboratory production [2,3]. As a result, proficiency in digital workflows, including CAD/CAM, has become indispensable for future dental professionals [1].

To prepare for these changes, dental curricula have increasingly integrated digital dentistry modules [4,5]. Many institutions now provide preclinical education in intraoral scanning and CAD-/CAM-based prosthesis fabrication, allowing students to experience both conventional and digital approaches [4,5]. Previous studies have demonstrated that students positively perceived the inclusion of digital dentistry in preclinical training and regarded it as educationally beneficial [6]. Moreover, the integration of digital technologies into dental education has been emphasized for its potential to improve learning outcomes and better prepare graduates for modern practice [7]. Accordingly, high-quality training in CAD/CAM and related technologies is essential to develop practice-ready graduates [4,7].

Nevertheless, several reports indicate that many students do not feel adequately trained or confident in the use of CAD/CAM [8,9]. Previous reports found that 96% of students had no CAD/CAM experience outside formal lectures, and the majority perceived their training as insufficient [10]. These findings suggest that current curricula may not provide sufficient depth or hands-on experience to ensure proficiency in digital dentistry.

As dental education expands its workflow to include digital fabrication, the demand for CAD/CAM capabilities is increasing [11,12]. A recent study of Chinese dental technology undergraduates found that over 80% of students found digital dentistry courses beneficial for their learning and career preparation [13]. Furthermore, the majority of fourth-year students reported that they still lacked the confidence to independently complete digital dental designs [13]. These results highlight the need for ongoing curricular development to meet contemporary digital standards. In dental hygiene education, digital competencies are also being incorporated. Naderi et al. introduced intraoral scanners into dental hygiene curricula and reported that digital impressions demonstrated significantly higher quality than conventional alginate impressions [14]. Importantly, even first-year dental hygiene students with minimal clinical experience were able to learn intraoral scanning and produce accurate digital models [14]. Similarly, Roth et al. found that repeated digital impressions improved scanning proficiency and efficiency among inexperienced dental students [15]. Collectively, these findings suggest that students in dentistry-related fields respond positively to CAD/CAM education and that the early integration of digital dentistry is advantageous. However, few studies have simultaneously examined dental hygiene and dental technology students to compare CAD/CAM educational experiences and competencies.

Therefore, the aim of this study was to evaluate CAD/CAM educational experiences and utilization competencies among dental hygiene and dental technology students, and to analyze differences according to major and grade level. By identifying these differences, the study aimed to provide baseline evidence for curriculum improvement and the development of interdisciplinary digital dentistry education.

2. Materials and Methods

2.1. Study Design and Participants

This cross-sectional descriptive study was approved by the Institutional Review Board of Dongnam Health University (IRB No. 1044371-202409-HR-006-01) and conducted among undergraduate students in Gyeonggi Province, Korea. Sample size was calculated using G*Power 3.1.9.2 for chi-square tests, with a significance level of 0.05, a medium effect size of 0.30, and a power of 0.95. The minimum required sample size was 368, and considering a 20% dropout rate, the final target sample was set at 460. The recruitment process involved distributing the survey link through official departmental communication channels to all enrolled students in the dental hygiene and dental technology programs. A total of 480 students participated, and after excluding incomplete responses, 464 valid responses were included, yielding a response rate of 96.7%. All participants were enrolled in dental

hygiene or dental technology programs and voluntarily consented to participate after being informed of the study purpose and procedures. Data collection was conducted via an online platform (Google Form, Google Co., Mountain View, CA, USA) between September 30 and 31 October 2024, and all responses were anonymous.

2.2. Measurements

The questionnaire was adapted and modified from validated items used in previous studies [6,8] and revised to suit the objectives of this research. Content validity was confirmed through review by two dental hygiene professors, two dental technology professors, and one clinical dentist. In addition, prior to the main survey, a pilot test involving 20 students was conducted to verify comprehension, clarity, and content validity of the questionnaire. The final questionnaire comprised a total of 19 items and included a combination of dichotomous (yes/no), multiple-response, and 5-point Likert scale items depending on the characteristics of each domain. Items on general characteristics and CAD/CAM education experience used categorical or binary response formats, while competency-related items (scanner utilization, CAD design, CAM operation, and post-processing) were measured using a 5-point Likert scale (1 = very low, 5 = very high). Scanning, CAD, and CAM application items allowed multiple selections to reflect the range of digital tasks performed by students. The final questionnaire consisted of 19 items across the following domains: (1) general characteristics, (2) CAD/CAM education experience, (3) scanner utilization competency, (4) CAD design competency, (5) CAM operation competency, and (6) post-processing competency.

2.3. Statistical Analysis

Data analysis was performed using SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY, USA). General characteristics were summarized with descriptive statistics and frequency analysis. CAD/CAM education experience and competencies in scanning, CAD design, CAM operation, and post-processing were examined according to major and grade level using cross-tabulation and independent-samples *t*-tests. Pearson's correlation analysis was applied to assess associations among competencies. Pearson's correlation (p, rho) was interpreted according to commonly accepted guidelines: p (rho) = 0.00–0.19 was considered negligible, 0.20–0.39 weak, 0.40–0.59 moderate, 0.60–0.79 strong, and 0.80–1.00 very strong correlation. Normality was tested with the Shapiro–Wilk test, and homogeneity of variances was evaluated with Levene's test. Statistical significance was set at $p < 0.05$.

3. Results

3.1. CAD/CAM Education Experience by Major and Grade

Of the 464 respondents, 208 students (44.8%) reported prior CAD/CAM education experience. Dental technology students (N = 177, 87.2%) (Table 1) had a significantly higher rate of experience compared with dental hygiene students (N = 31, 11.9%) ($p < 0.001$, Table 1). Similarly, senior students (3rd–4th year, 57.8%) demonstrated a higher prevalence of CAD/CAM education compared with junior students (1st–2nd year, 39.0%) ($p < 0.001$, Table 1).

Table 1. CAD/CAM education experience by major and grade (N = 464).

Characteristics	CAD/CAM Education Experience		*p*-Value *
	Yes N (%)	No N (%)	
Major			
Dental Hygiene	31 (11.9)	230 (88.1)	<0.001
Dental Technology	177 (87.2)	26 (12.8)	

Table 1. *Cont.*

Characteristics	CAD/CAM Education Experience		*p*-Value *
	Yes N (%)	No N (%)	
Grade			
1–2 year	123 (39.0)	192 (61.0)	<0.001
3–4 year	86 (57.8)	63 (42.2)	

* *p*-values are from χ^2 test for categorical variables.

3.2. Scanning Utilization Competency by Major and Grade

The mean scanning competency score was significantly higher in dental technology students (3.53 ± 1.02) than in dental hygiene students (2.14 ± 0.97) ($p < 0.001$, Table 2). Senior students (3.22 ± 1.01) also scored higher than juniors (2.53 ± 0.95) ($p < 0.001$, Table 2).

Table 2. Scanning utilization competency and application by major and grade.

Characteristics	Major		*p*-Value	Grade		*p*-Value *
	Dental Hygiene (N = 261)	Dental Technology (N = 203)		Juniors 1–2 Year (N = 315)	Senior 3–4 Year (N = 149)	
Scanning utilization competency	2.14 ± 0.97	3.53 ± 1.02	<0.001	2.53 ± 0.95	3.22 ± 1.01	<0.001
# Applications of scanning						
Model scan	50 (19.2)	120 (59.1)		102 (32.4)	68 (45.6)	
Oral scan	114 (43.7)	45 (22.1)		106 (33.7)	53 (35.6)	
Impression scan	84 (32.2)	52 (25.6)		93 (29.8)	43 (28.5)	
Other	41 (15.7)	4 (2.0)		39 (12.3)	6 (4.0)	
Not possible	66 (25.3)	4 (2.0)		62 (19.9)	8 (5.4)	

* *p*-values are from independent *t*-test for continuous variables. # Multiple responses were allowed.

For scanning applications (multiple responses permitted), model scanning (36.6%) and intraoral scanning (34.3%) were the most frequently reported. Dental technology students predominantly reported model scanning (59.1%), while dental hygiene students reported intraoral (43.7%) and impression scanning (32.2%) more frequently. Senior students indicated a higher proportion of model scanning compared with juniors.

3.3. CAD/CAM Utilization Competency by Major and Grade

CAD design competency was significantly higher in dental technology students (3.33 ± 1.05) than in dental hygiene students (1.93 ± 0.88) ($p < 0.001$, Table 3). Seniors (3.12 ± 1.04) also scored higher than juniors (2.05 ± 0.91) ($p < 0.001$, Table 3). The most frequently used CAD applications were Exocad (33.0%) and 3Shape (19.2%). The most common design outputs included inlay/crown/cap restorations, followed by implant-supported designs (36.5%), partial dentures, and orthodontic appliances.

Table 3. CAD/CAM utilization competency and application by major and grade.

Characteristics	Major		*p*-Value	Grade		*p*-Value *
	Dental Hygiene (N = 261)	Dental Technology (N = 203)		Juniors 1–2 Year (N = 315)	Senior 3–4 Year (N = 149)	
CAD design competency	1.93 ± 0.88	3.33 ± 1.05	<0.001	2.05 ± 0.91	3.12 ± 1.04	<0.001
# Applications of CAD design						
EXO (Exocad)	7 (2.7)	99 (48.8)		85 (18.3)	68 (14.7)	
3Shape	20 (7.7)	23 (11.3)		39 (8.4)	50 (10.8)	
Other	3 (1.1)	1 (0.5)		6 (1.3)	5 (1.1)	
# Part of CAD design						
Inlay/Crown/Cap	27 (10.3)	150 (73.9)		95 (38.2)	82 (32.9)	
Implant	23 (8.8)	68 (33.5)		33 (13.3)	58 (23.3)	
Partial denture	10 (3.8)	28 (13.8)		16 (6.4)	22 (8.8)	
Full denture	16 (6.1)	24 (11.8)		21 (8.4)	19 (7.6)	
Orthodontics	18 (6.9)	16 (7.9)		14 (5.6)	20 (8.0)	
CAM operation competency	1.91 ± 0.82	2.64 ± 0.94	<0.001	2.01 ± 0.83	2.71 ± 0.92	<0.001

Table 3. *Cont.*

Characteristics	Major		*p*-Value	Grade		*p*-Value *
	Dental Hygiene (N = 261)	Dental Technology (N = 203)		Juniors 1–2 Year (N = 315)	Senior 3–4 Year (N = 149)	
# Applications of Milling program						
Huprerdent	10 (3.8)	19 (9.4)		18 (5.7)	11 (7.4)	
Millbox	32 (12.3)	51 (25.1)		41 (13.0)	42 (28.2)	
Not possible	44 (16.9)	62 (30.5)		61 (19.4%)	45 (30.2%)	
# 3D Printer Field						
FDM	22 (8.4)	32 (15.8)		35 (11.1)	19 (12.8)	
DLP	18 (6.9)	20 (9.9)		28 (8.9)	10 (6.7)	
Not possible	44 (16.9)	56 (27.6)		59 (18.7)	41 (27.5)	
# Applications of 3D Printer						
Temporary crown	28 (10.7)	46 (22.7)		39 (12.4)	35 (23.5)	
Surgical stent	15 (5.7)	9 (4.4)		17 (5.4)	7 (4.7)	
Burn out resin	14 (5.4)	14 (6.9)		18 (5.7)	10 (6.7)	
Study model	10 (3.8)	12 (5.9)		14 (4.4)	8 (5.4)	
Not possible	49 (18.8)	49 (24.1)		57 (18.1)	41 (27.5)	

* *p*-values are from independent *t*-test for continuous variables. # Multiple responses were allowed.

CAM operation competency was also significantly greater in dental technology students (2.64 ± 0.94) compared with dental hygiene students (1.91 ± 0.82) ($p < 0.001$, Table 3). Seniors (2.71 ± 0.92) outperformed juniors (2.01 ± 0.83) ($p < 0.001$, Table 3). The most frequently reported CAM applications were Millbox (25.1%) and FDM (15.8%). Temporary crowns (22.7%) were the most common 3D printing outputs.

3.4. Post-Processing Competency by Major and Grade

Post-processing competency was significantly higher in dental technology students (2.77 ± 1.14) than in dental hygiene students (1.95 ± 1.08) ($p < 0.001$, Table 4). Senior students (2.73 ± 1.32) also achieved higher scores than juniors (2.12 ± 1.05) ($p < 0.001$, Table 4).

Table 4. Post-processing competency, zirconia coloring, and staining by major and grade.

Characteristics	Major		*p*-Value	Grade		*p*-Value *
	Dental Hygiene (N = 261)	Dental Technology (N = 203)		Juniors 1–2 Year (N = 315)	Senior 3–4 Year (N = 149)	
Post-processing competency	1.95 ± 1.08	2.77 ± 1.14	<0.001	2.12 ± 1.05	2.73. ± 1.32	<0.001
Zirconia coloring	1.95 ± 1.09	2.84 ± 1.19	<0.001	2.11 ± 1.08	2.82 ± 1.35	<0.001
Zirconia staining	1.98 ± 1.11	2.78 ± 1.14	<0.001	2.10 ± 1.05	2.82 ± 1.32	<0.001

* *p*-values are from independent *t*-test for continuous variables.

Both zirconia coloring and staining competencies were significantly greater in dental technology students than in dental hygiene students ($p < 0.001$, Table 4). Senior students consistently scored higher than juniors in both areas ($p < 0.001$, Table 4).

3.5. Correlation Between Scanning, CAD/CAM, and Post-Processing Competencies

Correlation analysis revealed significant positive associations among all competency domains ($p < 0.01$, Table 5). Scanning competency was strongly correlated with CAD design competency (r = 0.686) and moderately correlated with CAM operation (r = 0.505) and post-processing (r = 0.501). CAD design competency demonstrated strong correlations with CAM operation (r = 0.607), zirconia coloring (r = 0.611), and zirconia staining (r = 0.595). CAM operation competency was strongly associated with post-processing (r = 0.730), zirconia coloring (r = 0.706), and zirconia staining (r = 0.695). Post-processing competency exhibited very strong correlations with zirconia coloring (r = 0.854) and zirconia staining (r = 0.853).

Table 5. Correlation between scanning, CAD/CAM, and post-processing competencies.

	Scanning Competency	CAD Competency	CAM Operation Competency	Post-Processing Competency	Zirconia Coloring	Zirconia Staining
Scanning competency	1					
CAD design competency	0.686 **	1				
CAM operation competency	0.505 **	0.607 **	1			
Post-processing competency	0.501 **	0.580 **	0.730 **	1		
Zirconia coloring	0.494 **	0.611 **	0.706 **	0.854 **	1	
Zirconia staining	0.474 **	0.595 **	0.695 **	0.853 **	0.940 **	1

** $p < 0.01$ by Pearson's correlation analysis.

4. Discussion

The application of CAD/CAM technology has expanded in modern dentistry, yet differences may exist in educational experiences and competencies between dental hygiene and dental technology students [16]. This study aimed to compare these CAD/CAM educational exposures and practical abilities between the two majors. The results revealed statistically significant differences in educational experience and competencies for each digital task. These differences are interpreted as a reflection of the unique job characteristics and educational orientations of each major.

A prominent finding of this study is the significant disparity in CAD/CAM educational experience based on major. While 87.2% of dental technology students reported having received such education, only 11.9% of dental hygiene students had the same experience. This reflects the current reality where CAD/CAM technology is a core competency in the traditional role of a dental technologist, which focuses on prosthetic fabrication. In contrast, the role of a dental hygienist is primarily centered on oral environment management and clinical assistance, leading to a slower adoption of digital equipment training [17,18]. This educational imbalance could potentially cause information gaps or communication difficulties in future digital collaborations between the two professions, highlighting an urgent need to strengthen the dental hygiene curriculum to foster digital literacy.

These educational disparities are also reflected in specific digital technology application competencies. In the scanning process, dental technology students showed the most confidence in 'model scan' (59.1%), whereas dental hygiene students more frequently chose 'oral scan' (43.7%) and 'impression scan' (32.2%). This is a natural outcome reflecting that dental technologists primarily work based on models [19], while dental hygienists perform the clinical role of acquiring data directly from the patient's oral cavity [20]. Similarly, in CAD design, CAM operation, and post-processing abilities, the scores of dental technology students were significantly higher than those of dental hygiene students across all items. This clearly demonstrates that the entire process of designing and fabricating the physical form of prosthetics falls within the unique domain of dental technologists. While it is expected that dental hygiene students would show lower competency in these areas, a basic understanding of the design and fabrication process is necessary for them to comprehend the overall digital workflow and communicate effectively with dental laboratories.

The study also found a significant trend of improvement in all digital competency scores as students progressed to higher academic years. For instance, 3rd–4th year students demonstrated significantly higher abilities in scanning, CAD design, CAM operation, and post-processing compared to 1st–2nd year students. This indicates that the current curriculum is effectively enhancing students' CAD-/CAM-related knowledge and skills as they advance in their studies, suggesting that a systematic and progressive educational approach tailored to each academic level is effective [21,22]. Therefore, universities should solidify a tiered educational strategy—introducing digital dentistry and sparking interest in the lower grades, while cultivating practical clinical and technical skills through advanced labs in the upper grades.

Furthermore, the correlation analysis offers significant educational implications. A significant positive correlation was found among all competency variables, including scanning, CAD design, CAM operation, and post-processing ($p < 0.01$). Scanning ability showed a high correlation with CAD design ability (r = 0.686), and CAM operation ability was strongly correlated with post-processing ability (r = 0.730). This clearly demonstrates that digital dentistry technology is not a mere sum of discrete skills but an integrated workflow, from data acquisition to design, manufacturing, and finishing [23,24]. This implies that proficiency in one stage directly impacts the quality and efficiency of the subsequent stages [25]. These findings suggest that a Project-Based Learning (PBL) approach, where students experience the entire process through a single project or case, could be more effective than teaching each skill in isolation.

Recent advancements in artificial intelligence (AI) have further accelerated these changes in digital dentistry. AI-based design systems are now capable of generating automated restoration and crown designs with clinically acceptable accuracy, as demonstrated in studies evaluating AI-designed single-molar prostheses [26]. In addition, AI algorithms have shown potential in predicting the debonding or failure of CAD/CAM restorations, suggesting a future in which AI supports both design and quality assurance processes in digital workflows [27]. The increasing precision of 3D-printed dental models, supported by studies assessing dimensional accuracy and surface characteristics [28], further underscores the need for CAD/CAM education to incorporate AI literacy and emerging digital fabrication standards. As these technologies continue to evolve, dental hygiene and dental technology curricula must prepare students to work competently within AI-enhanced CAD/CAM environments.

Nevertheless, this study has several limitations. The study's participants were limited to students from a few universities in Gyeonggi Province, which calls for caution when generalizing the findings. Additionally, students' competencies were measured through self-reported surveys, which may not perfectly reflect their actual performance abilities. Finally, the cross-sectional design makes it difficult to establish a clear causal relationship for the observed differences. Future research should expand the sample size to a national scale and introduce multifaceted evaluation methods, such as performance tests or portfolio analyses. Longitudinal studies that track students' competency changes after implementing specific educational programs would also be meaningful for developing and validating effective CAD/CAM educational models.

An essential educational implication emerging from these findings is the evolving scope of digital dentistry [29]. As intraoral scanners, CAD platforms, and additive manufacturing technologies become increasingly embedded in everyday dental practice, the traditional boundaries between clinical and technical roles are gradually converging. Although dental hygienists are not primarily responsible for prosthetic fabrication, their role increasingly involves patient education, effective communication with dental technologists, and supportive care within a digital workflow [30]. Consequently, cultivating at least a foundational level of CAD/CAM literacy among dental hygiene students should not be regarded as optional but rather as essential for fostering interdisciplinary collaboration and ensuring patient-centered care.

In addition, the growing integration of digital competencies across international dental curricula underscores the importance of aligning domestic educational strategies with global trends [31]. The competency gap observed in this study highlights the value of introducing interprofessional education models, in which dental hygiene and dental technology students jointly engage in digital case projects. Such collaborative training would not only simulate real-world practice but also enhance mutual understanding of each profession's contributions, ultimately strengthening the quality and efficiency of digital dentistry services. These findings further indicate the need for a more structured and progressive curriculum that provides foundational digital exposure for dental hygiene stu-

dents and advanced, practice-oriented training for dental technology students, supporting both groups as they prepare for AI-enhanced digital workflows.

5. Conclusions

In conclusion, this study empirically confirms that there are clear differences in CAD/CAM technology educational experiences and competency levels between dental hygiene and dental technology students. The findings suggest that dental technology education should continue to focus on fabrication-centered advanced training, while dental hygiene education should strengthen its focus on clinical data acquisition. At the same time, as digital dentistry is accomplished through the close collaboration of various professionals, this study strongly suggests the importance of developing integrated and interlinked curricula based on an understanding of each other's roles. It is hoped that the findings of this study will serve as valuable foundational data for developing effective digital dentistry curricula to train future dental professionals.

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Abbreviation

The following abbreviations are used in this manuscript:

CAD/CAM	computer-aided design/computer-aided manufacturing

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