**Original article**

**doi:10.5633/amm.2026.0311**

# Comparative analysis of convergence angles in tooth preparations during preclinical training

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The convergence angle, also known as Total Occlusal Convergence (TOC), is a key factor influencing the retention and resistance of fixed prosthetic restorations and represents the total angle between two opposing axial surfaces of a prepared tooth (mesial and distal or buccal and oral). The aim of this study was to determine the convergence angles of acrylic teeth prepared by dental students during preclinical training and to compare the obtained values among different tooth groups. Measurements were performed using the CAD/CAM system ExoCAD through digital analysis of surface inclination relative to the path of insertion, assessing vestibulo-oral (VO) and mesio-distal (MD) convergence angles in 30 teeth for each tooth group. The lowest mean values were recorded in canines (VO: 11.13 ± 1.31°; MD: 11.53 ± 1.85°), while incisors showed similar values (VO: 12.20 ± 2.01°; MD: 12.10 ± 1.83°). Premolars demonstrated higher values compared to anterior teeth (VO: 17.77 ± 3.07°; MD: 19.73 ± 3.36°), whereas the highest mean values were observed in molars (VO: 21.37 ± 3.72°; MD: 21.37 ± 3.17°). The obtained results indicate that convergence angles achieved during preclinical training exceed the values recommended in the literature,

suggesting the need for improved standardization and control of tooth preparation techniques during dental education.

*Keywords: convergence angle; tooth preparation; preclinical training; CAD/CAM analysis*

**Originalni rad**

**doi:10.5633/amm.2026.0311**

# Uporedna analiza uglova konvergencije preparisanih zuba na pretkliničkim vežbama

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Ugao konvergencije, poznat i kao ukupna okluzalna konvergencija (Total Occlusal Convergence – TOC), predstavlja ključni faktor koji utiče na retenciju i rezistenciju fiksnih protetskih nadoknada i definiše se kao ukupan ugao između dve naspramne aksijalne površine preparisanog zuba (mezijalne i distalne ili vestibularne i oralne). Cilj ovog istraživanja bio je određivanje uglova konvergencije akrilatnih zuba preparisanih od strane studenata stomatologije tokom pretkliničke nastave, kao i poređenje dobijenih vrednosti između različitih grupa zuba. Merenja su izvršena korišćenjem CAD/CAM sistema ExoCAD, digitalnom analizom nagiba površina u odnosu na pravac unošenja, pri čemu su procenjivani vestibulo-oralni (VO) i mezio-distalni (MD) uglovi konvergencije na 30 zuba u svakoj grupi. Najniže srednje vrednosti zabeležene su kod očnjaka (VO: 11,13 ± 1,31°; MD: 11,53 ± 1,85°), dok su sekutići pokazali slične vrednosti (VO: 12,20 ± 2,01°; MD: 12,10 ± 1,83°). Premolari su imali više vrednosti u odnosu na prednje zube (VO: 17,77 ± 3,07°; MD: 19,73 ± 3,36°), dok su najviše srednje vrednosti registrovane kod molara (VO: 21,37 ± 3,72°; MD: 21,37 ± 3,17°). Dobijeni rezultati ukazuju da su uglovi konvergencije ostvareni

tokom pretkliničke nastave veći od vrednosti preporučenih u literaturi, što ukazuje na potrebu za unapređenjem standardizacije i kontrole tehnike preparacije zuba u okviru stomatološke edukacije.

*Ključne reči: konvergencioni ugao; preparacija zuba; pretklinička nastava; CAD/CAM analiza*

## Introduction

Artificial crowns, as fixed prosthetic restorations, are fabricated to restore the morphology and function of damaged tooth structure (fractures, caries, discoloration, and shape alterations), or to serve as abutments for fixed dental prostheses (bridges) in cases of tooth loss.

Tooth preparation, or grinding, involves the removal of hard dental tissues to create sufficient space for the fabrication of an artificial crown. This procedure should be minimally invasive, meaning that only the necessary amount of tooth structure is removed. The extent of reduction depends on the material used for crown fabrication (metal alloy, metal-ceramic, or all-ceramic). Regardless of the material, the preparation design must ensure stable seating of the crown on the abutment tooth during oral function. In didactic terms, the crown must exhibit optimal retention and resistance. Retention is defined as the ability of a crown to resist forces that attempt to dislodge it in a direction opposite to its path of insertion (vertical forces, e.g., sticky food). Factors affecting retention include the height, surface area, and roughness of the prepared tooth (directly proportional to these factors), the type of cement, and the taper of the tooth preparation (1, 2, 3). Good retention is usually accompanied by optimal resistance, which refers to the ability of a crown to withstand oblique and apical forces that may cause tipping or rotation (4).

For adequate retention and resistance, the convergence angle, or Total Occlusal Convergence (TOC), is of great importance. It represents the total angle formed between two opposing axial surfaces of a prepared tooth (mesial and distal or buccal and oral) (5).

For maximum retention and resistance, ideally, no taper should exist, meaning that opposing walls of the prepared tooth should be parallel. However, this is not achievable in clinical practice. Theoretically ideal convergence values are 4–6°, while clinically acceptable values range from 6–12°. Values exceeding 15–20° significantly reduce retention. In cases of short clinical crowns, the convergence angle should be smaller, meaning that the axial walls should be more parallel (6, 7, 8).

Convergence is also important as it facilitates clinical procedures, including insertion and removal of the crown in the patient's mouth and in the dental laboratory, prevents undercuts, and allows easier cementation (9, 10).

The magnitude of TOC depends on the operator's experience. Literature data indicate that dental students and young practitioners often produce preparations with convergence angles that may compromise the retention and resistance of the prosthetic restoration (2, 11, 12).

The aim of this study was to determine the convergence angles of acrylic teeth prepared by dental students during preclinical training and to compare the obtained values among different groups of teeth.

## Materials and Methods

### Study Design

This study was designed as an analytical, observational study aimed at evaluating the total occlusal convergence (TOC) angle among different groups of teeth. The vestibulo-oral (VO) and mesio-distal (MD) convergence angles were analyzed in incisors, canines, premolars, and molars.

A total of 30 teeth were analyzed in each group.

### Measurement of Convergence Angle

Measurements were carried out using a CAD/CAM system (ExoCAD), through digital analysis of surface inclinations relative to the preparation axis. For each tooth, two convergence values were determined: VO and MD. The total occlusal convergence (TOC) angle was calculated as the arithmetic mean of VO and MD values.

For additional analysis, teeth were categorized into two groups:

- anterior teeth (incisors and canines),
- posterior teeth (premolars and molars).

**Statistical Analysis**

Statistical analysis was performed using IBM SPSS Statistics software, version 30.0 (IBM Corp., Armonk, NY, USA). Prior to applying parametric tests, data distribution normality was assessed using the Shapiro–Wilk test. Since the data did not show a statistically significant deviation from normal distribution ($p > 0.05$), parametric statistical tests were applied. Descriptive statistics included calculation of the mean ($\bar{X}$) and standard deviation (SD) for VO and MD values within each tooth group. Differences between VO and MD values within the same group were analyzed using the paired Student's *t*-test. Comparisons of convergence angles among different tooth groups were performed using one-way analysis of variance (ANOVA). When statistically significant differences were found, post hoc analysis with Bonferroni correction was conducted to identify intergroup differences. Differences between anterior and posterior teeth were analyzed using the independent Student's *t*-test. The level of statistical significance was set at $p < 0.05$.

**Results**

**Descriptive statistics of results**

The data were initially analyzed using descriptive statistics. Mean values and standard deviations of VO and MD convergence angles were calculated for each tooth group (Table 1).

Table 1. Descriptive statistics of VO and MD convergence angle values

| Group | VO (X ± SD) | MD (X ± SD) |
|---|---|---|
| Incisors | 12.20 ± 2.01 | 12.10 ± 1.83 |
| Canines | 11.13 ± 1.31 | 11.53 ± 1.85 |
| Premolars | 17.77 ± 3.07 | 19.73 ± 3.36 |
| Molars | 21.37 ± 3.72 | 21.37 ± 3.17 |

The lowest mean values were observed in canines (VO: 11.13 ± 1.31°; MD: 11.53 ± 1.85°), while the highest values were recorded in molars (VO: 21.37 ± 3.72°; MD: 21.37 ± 3.17°). In incisors, the mean values were 12.20 ± 2.01° in the VO direction and 12.10 ± 1.83° in the MD direction. Premolars showed higher values compared to anterior teeth (VO: 17.77 ± 3.07°; MD: 19.73 ± 3.36°).

**Comparison between individual tooth groups**

One-way analysis of variance (ANOVA) was used to compare convergence angles among different tooth groups, revealing a statistically significant difference between groups ($p < 0.001$). To further identify intergroup differences, post hoc analysis with Bonferroni correction was performed, and the results are graphically presented in Figures 1–4.

Figure 1 presents the mean convergence angle values with 95% confidence intervals (CI), with incisors used as the reference group. Incisors exhibited statistically significantly lower values compared to premolars and molars ($p < 0.001$), while no statistically significant difference was found compared to canines ($p > 0.05$).

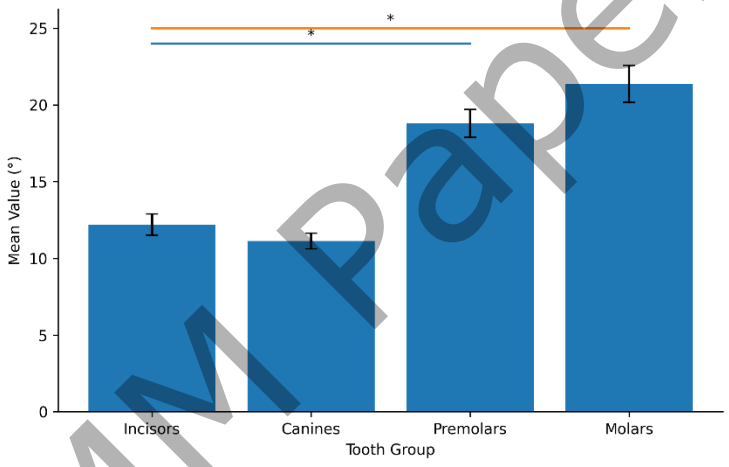


**Figure 1.** Post hoc Bonferroni comparison of convergence angles with incisors as the reference group. Mean values are presented with 95% confidence intervals (CI). Statistically significant differences are indicated by an asterisk (p < 0.05).

Figure 2 shows the mean convergence angle values with 95% confidence intervals (CI), using canines as the reference group. Canines demonstrated significantly lower values compared to premolars and molars ($p < 0.001$), whereas the difference compared to incisors was not statistically significant ($p > 0.05$).

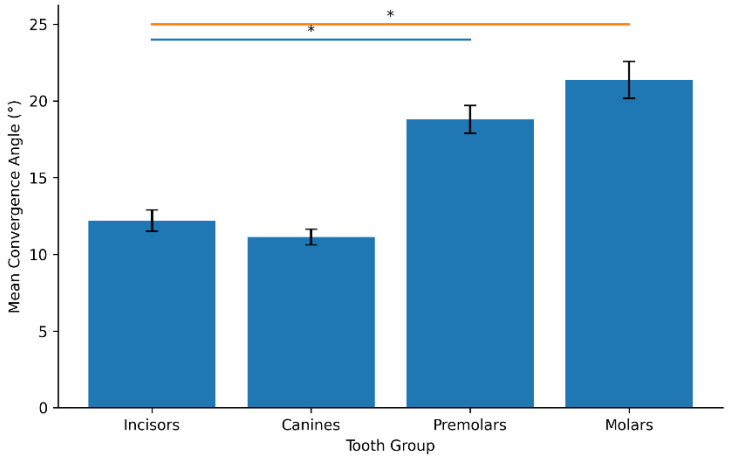


**Figure 2**. Post hoc Bonferroni comparison of total occlusal convergence angles with canines as the reference group. Mean values are presented with 95% confidence intervals (CI). Statistically significant differences are indicated by an asterisk ($p < 0.05$).

Figure 3 illustrates the mean total occlusal convergence values with 95% confidence intervals (CI), with premolars as the reference group. Premolars showed significantly higher values compared to incisors and canines ($p < 0.001$), but significantly lower values compared to molars ($p < 0.05$).

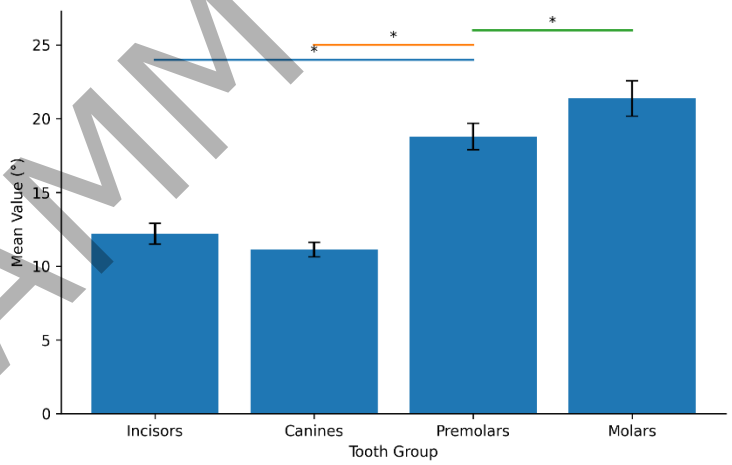

**Figure 3.** Post hoc Bonferroni comparison of total occlusal convergence angles with premolars as the reference group. Mean values are presented with 95% confidence intervals (CI). Statistically significant differences are indicated by an asterisk (*p < 0.05).

Figure 4 presents the mean total occlusal convergence values with 95% confidence intervals (CI), with molars as the reference group. Molars exhibited significantly higher convergence angle values compared to all other tooth groups ($p < 0.05$).

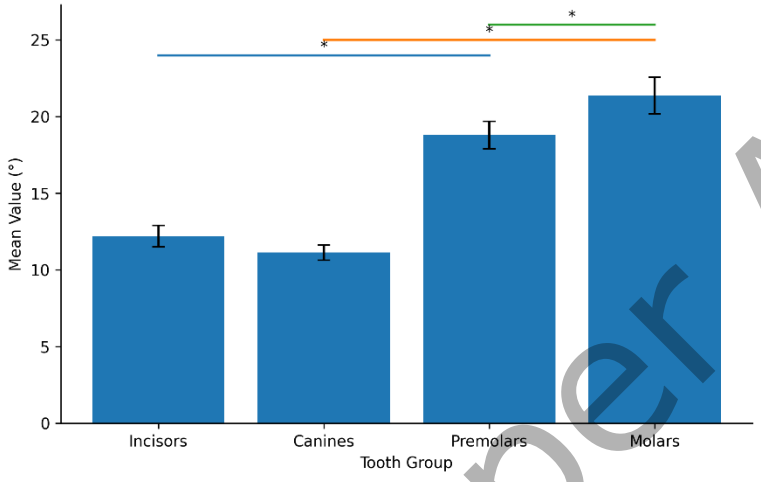


**Figure 4.** Post hoc Bonferroni comparison of total occlusal convergence angles with molars as the reference group. Mean values are presented with 95% confidence intervals (CI). Statistically significant differences are indicated by an asterisk (p < 0.05).

Overall, a progressive increase in convergence angles was observed from anterior to posterior teeth.

Additionally, teeth were grouped into two categories: anterior and posterior. Differences between these groups were analyzed using the independent Student's t-test.

**Comparison between anterior and posterior teeth**

A statistically significant difference was found between anterior and posterior teeth (p < 0.001), with posterior teeth exhibiting significantly higher convergence angle values (Figure 5).

Figure 5 shows the distribution of mean total occlusal convergence values with 95% confidence intervals (CI) for anterior and posterior teeth. The analysis demonstrated significantly higher values in posterior teeth compared to anterior teeth ($p < 0.001$).

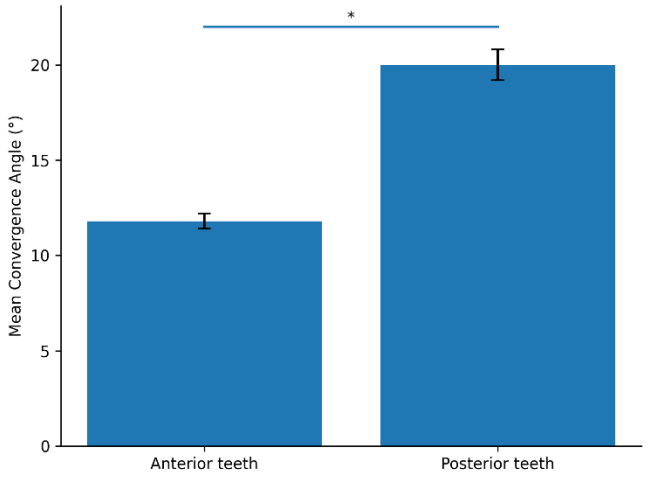


**Figure 5.** Comparison of total occlusal convergence angles between anterior and posterior teeth. Mean values are presented with 95% confidence intervals (CI). A statistically significant difference between groups is indicated by an asterisk ($p < 0.05$).

These findings further confirm the trend of increasing convergence angles from anterior to posterior regions.

**Discussion**

The study was based on the hypothesis that second-year dental students, when preparing teeth on phantom models, produce higher convergence angle values than those reported in the literature .

The convergence angles of teeth prepared during preclinical exercises were higher than the values recommended in the literature. The lowest mean values were observed in canines (VO: 11.13 ± 1.31°; MD: 11.53 ± 1.85°), while incisors showed similar, slightly higher values (VO: 12.20 ± 2.01°; MD: 12.10 ± 1.83°). Premolars demonstrated more pronounced convergence angles (VO: 17.77 ± 3.07°; MD: 19.73 ± 3.36°), whereas the highest mean values were recorded in molars (VO: 21.37 ± 3.72°; MD: 21.37 ± 3.17°).

A statistically significant difference was confirmed between anterior and posterior teeth ($p < 0.001$), with posterior teeth exhibiting significantly higher convergence angles.

These findings may be explained by insufficient control of the parallelism of opposing axial walls during tooth preparation, as well as the fear that the crown may not seat properly or may not seat properly or may interfere during insertion. Additionally, limited visual assessment on phantom models—and consequently intraorally—contributes to these results, which may largely be attributed to operator inexperience.

Experience clearly plays a crucial role in achieving optimal convergence angles. This can be explained by visual training (the ability to recognize parallelism in three-dimensional space), improved hand control and bur manipulation (fine motor movements reduce excessive taper), and proper treatment planning (establishing the path of insertion prior to preparation). Therefore, teaching protocols emphasize the use of less tapered burs, adherence to theoretical preparation principles, and frequent evaluation of parallelism using mirrors or silicone indices. Achieving an optimal convergence angle and overall preparation quality requires continuous training and skill development.

Previous studies have also investigated the visual assessment of convergence angles to determine whether clinical experience influences the clinician's ability to evaluate preparation quality and predict the long-term success of prosthetic therapy. *Nick et al.* demonstrated that both dental students and faculty have limited accuracy in estimating total occlusal convergence, with considerable variability in their assessments (13). *Strain et al.* reported a significant difference between inexperienced individuals and those with experience in fixed prosthodontics in their ability to visually assess total occlusal convergence (14). In contrast, *Mays et al.* found that students and instructors demonstrated similar accuracy, with both groups being less precise when assessing larger convergence angles compared to smaller ones (15).

A more accurate and reliable assessment of convergence angles can be achieved using CAD/CAM (Computer-Aided Design/Computer-Aided Manufacturing) systems, particularly when aiming to reduce subjectivity associated with visual evaluation and obtain quantitative data. Digital models allow simulation of different convergence angles and assessment of their impact on crown retention and stability prior to fabrication. CAD/CAM systems can also be utilized in dental education, enabling students to visually compare their preparations with ideal convergence values, thereby enhancing learning and improving precision. Using

laboratory or intraoral scanners, a 3D CAD model of each preparation is generated, and specialized software automatically measures the angle between axial walls and the tooth axis (TOC) in both buccolingual and mesiodistal directions (15, 16). This methodology was also applied in the present study.

A study conducted by *Yoon et al.* at the Harvard School of Dental Medicine demonstrated significant evidence of excessive convergence angles compared to ideal values across three different tooth types (incisor, premolar, and molar) and four planes (12.7–19.1°). Molar preparations showed the highest mean convergence values, while incisor preparations in the mesiodistal direction were within optimal ranges (4.1–8.0°) (17).

Comparative analysis of convergence angles across three universities in the United States, Egypt, and Saudi Arabia revealed the highest mean convergence values in buccolingual measurements among Egyptian students (19.8 ± 10.0°) and the lowest mean values in mesiodistal measurements among Saudi students (14.1 ± 3.8°). These values significantly deviated from the recommended range of 4–12° (18).

Marghalani reported that the mean convergence angles achieved by students ranged between 10.16° and 11.46°, with only a few students reaching ideal values. No significant differences were observed between male and female students in buccolingual and mesiodistal convergence angles (19).

A systematic review investigating convergence angle values achieved by dental students during crown preparation analyzed studies from multiple databases, including Medline, Embase, Web of Knowledge, Cochrane Library, British Dental Journal, and the Journal of the American Dental Association. Twelve studies from 11 countries (published between 1978 and 2014) were included, encompassing 2,306 preparations. The results indicated that students generally failed to achieve ideal convergence angles (4°–14%) but produced clinically acceptable values (10°–20°) (20).

*Rafeek et al.* reported mean mesiodistal convergence angles of 20.3 ± 11.3° and buccolingual angles of 18.3 ± 8.5° in a study conducted at a university in Jamaica (21).

A study conducted in the United Kingdom reported mean buccolingual convergence angles of 19.6° ± 11.7 and mesiodistal angles of 17.8° ± 11.1. The lowest values were observed in canines, and the highest in

molars. Clinically acceptable angles (10–20°) were achieved in 30% of buccolingual and 40% of mesiodistal preparations (22).

When compared with studies evaluating convergence angles in preparations performed by 154 dentists in private practice in Dubai, dental students demonstrated greater precision. The mean mesiodistal convergence angle was 24.6° ± 11.8°, and the mean buccolingual angle was 32.6° ± 15.3°, with an overall TOC of 28.6°. Both buccolingual and mesiodistal angles significantly exceeded clinically acceptable values (10°–22°). The lowest TOC values were recorded in premolars (23).

This study is limited by its in vitro design and the use of acrylic teeth, which may not fully replicate clinical conditions, as well as by the absence of factors such as saliva, patient movement, and intraoral visibility constraints.

**Conclusion**

Convergence angles of teeth prepared during preclinical exercises were higher than the values recommended in the literature. The lowest mean values were recorded in canines and incisors, while the highest angles were observed in molars, followed by premolars. A statistically significant difference was confirmed between anterior and posterior teeth, with posterior teeth exhibiting more pronounced convergence angles. These findings suggest that controlling the inclination of axial walls is more challenging in posterior teeth and that greater precision in tooth preparation is achieved with increasing clinical experience. These findings highlight the need for improved training protocols and objective assessment methods in preclinical dental education.

**References**


1. Sato T, Al Mutawa N, Okada D, Hasegawa S. A clinical study on abutment taper and height of full cast crown preparations. J Med Dent Sci. 1998 Sep;45(3):205-10.

2. Ersu B, Narin D, Aktas G, Yuzugullu B, Canay S. Effect of preparation taper and height on strength and retention of zirconia crowns. Int J Prosthodont. 2012 Nov-Dec;25(6):582-4. PMID: 23101037.

3. Prause L, et al. Factors influencing retention of resin-based luting systems on implants: A systematic review. Dent Rev. 2022;2(3):100056. doi:10.1016/j.dentre.2022.100056.

4. Goodacre CJ, Campagni WV, Aquilino SA. Tooth preparations for complete crowns: an art form based on scientific principles. J Prosthet Dent. 2001 Apr;85(4):363-76. doi: 10.1067/mpr.2001.114685.

5. Mamoun JS. The total occlusal convergence of the abutment of a partial fixed dental prosthesis: A definition and a clinical technique for its assessment. Eur J Dent. 2013 Oct;7(4):509-513. doi: 10.4103/1305-7456.120665. PMID: 24932130.

6. Tiu J, Al-Amleh B, Waddell JN, Duncan WJ. Clinical tooth preparations and associated measuring methods: a systematic review. J Prosthet Dent. 2015 Mar;113(3):175-84. doi: 10.1016/j.prosdent.2014.09.007.

7. Alammari MR, Abdelnabi MH, Swelem AA. Effect of total occlusal convergence on fit and fracture resistance of zirconia-reinforced lithium silicate crowns. Clin Cosmet Investig Dent. 2018 Dec 31;11:1-8. doi: 10.2147/CCIDE.S193326.

8. Khamas MY, Al-Rawi I, Saleh AA. Computer-aided measurement of total occlusal convergence of teeth preparations for all-ceramic crowns by dental students. Indian J Forensic Med Toxicol. 2021;15(2):1744–1751. doi:10.37506/ijfmt.v15i2.14590.

9. Deranek K, Siegel SC, Golberg MB, Valdivieso AF. Tooth Preparation Assessment Criteria for All-Ceramic CAD/CAM Posterior Crowns: An Evidence Map. J Dent Educ. 2025 Oct;89(10):1464-1478. doi: 10.1002/jdd.13849.

10. Goodacre CJ, Campagni WV, Aquilino SA. Tooth preparations for complete crowns: an art form based on scientific principles. J Prosthet Dent. 2001 Apr;85(4):363-76. doi: 10.1067/mpr.2001.114685. PMID: 11319534.

11. Amine M, Wahid HO, Fahi S, Lehmouddi S, Hamza M, Elarabi S. Assessment of Convergence Angle of Tooth Preparations for Complete Crowns Among Dental Students: Typodont vs Simulator. Int J Dent. 2022 May 10;2022:7615892. doi: 10.1155/2022/7615892. PMID: 35592253; PMCID: PMC9113901.

12. Dündar B, Gönüldaş F, Akat B, et al. The effect of virtual reality simulators on tooth preparation skills of dental students. BMC Oral Health. 2025;25:422. doi:10.1186/s12903-025-05812-x.

13. Nick DR, Clark M, Miler J, Ordelheide C, Goodacre C, Kim J. The ability of dental students and faculty to estimate the total occlusal convergence of prepared teeth. J Prosthet Dent. 2009 Jan;101(1):7-12. doi: 10.1016/S0022-3913(08)60281-4.

14. Strain K, Horsfall L, Bonsor S, Ibbetson R. The Accuracy of Dental Students and Dentists Assessing the Total Occlusal Convergence of Crown Preparations. Eur J Prosthodont Restor Dent. 2020 May 28;28(2):86-93. doi: 10.1922/EJPRD_1984Strain07.

15. Mays KA, Crisp HA, Vos P. Utilizing CAD/CAM to Measure Total Occlusal Convergence of Preclinical Dental Students' Crown Preparations. J Dent Educ. 2016 Jan;80(1):100-7.

16. Schubert O, Erdelt KJ, Tittenhofer R, Hajtó J, Bergmann A, Güth JF. Influence of intraoral scanning on the quality of preparations for all-ceramic single crowns. Clin Oral Investig. 2020 Dec;24(12):4511-4518. doi: 10.1007/s00784-020-03316-2. Epub 2020 May 20. PMID: 32436159; PMCID: PMC7666666.

17. Yoon SS, Cheong C, Preisser J Jr, Jun S, Chang BM, Wright RF. Measurement of total occlusal convergence of 3 different tooth preparations in 4 different planes by dental students. J Prosthet Dent. 2014 Aug;112(2):285-92. doi: 10.1016/j.prosdent.2014.01.021.

18. Ayad MF, Maghrabi AA, Rosenstiel SF. Assessment of convergence angles of tooth preparations for complete crowns among dental students. J Dent. 2005 Sep;33(8):633-8. doi: 10.1016/j.jdent.2004.12.008.

19. Marghalani TY. Convergence angles of metal ceramic crowns prepared by dental students. J Prosthet Dent. 2014 Nov;112(5):1250-6. doi: 10.1016/j.prosdent.2014.03.024.

20. Strain KJ, Mackie J, Bonsor SJ, Macfarlane TV. Crown Taper Angles Achieved by Dental Students: A Systematic Review. J Dent Educ. 2018 Nov;82(11):1203-1212. doi: 10.21815/JDE.018.125.

21. Rafeek RN, Marchan SM, Seymour KG, Zou LF, Samarawickrama DY. Abutment taper of full cast crown preparations by dental students in the UWI School of Dentistry. Eur J Prosthodont Restor Dent. 2006 Jun;14(2):63-6.

22. Strain KJ, Tiu J, Mackie J, Bonsor SJ, Ibbetson RJ. Adequately Prepared? A Study Using an Innovative Computer Application to Measure Clinical Crown Convergence Angles Achieved by Students at a

UK Dental School. Eur J Prosthodont Restor Dent. 2019 Feb 22;27(1):32-38. doi: 10.1922/EJPRD_01832Strain07.

23. Abdulla F, Khamis H, Milosevic A, Abuzayda M. Convergence angles of all-ceramic full crown preparations performed in Dubai private practice. J Clin Exp Dent. 2018 Dec 1;10(12):e1192-e1197. doi: 10.4317/jced.55269.