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Original Article

Assessment of the taper angle in porcelain-fused-to-metal crown preparation performed by dental students: Study observational

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ABSTRACT

Introduction: Indirect restorations, such as fixed porcelain-fused-to-metal (PFM) crown and bridge prostheses, require tooth preparation that follows established principles to achieve restoration success. One of the preparation principles that needs to be considered is the taper angle, resulting from the axial wall tapering. To achieve maximum retention, the recommended taper angle is 6°. In clinical practice, preparation errors are frequently found, such as over-reduction and difficulties in axial tooth reduction. Thus, clinical education is required to improve students' competence and skills to achieve recommended and more precise preparation results. The aim of this study was to evaluate the taper angle of porcelain-fused-to-metal (PFM) crown preparations performed by dental students. **Methods:** The study was conducted using a descriptive observational design with a total sample of 30 patients at the Prosthodontics Department at RSGM Unpad treated by clinical students of FKG Unpad. The patients' jaws were scanned using a digital intraoral scanner, then the size of the taper angles were measured using CorelDRAW, with the ideal taper angle of 6-10°. The collected data were analyzed statistically using the chi-square test. **Results:** The average taper angle formed mesiodistally and buccolingually was 25,0° ± 14,5° and 14,9° ± 12,7° respectively, both of which were greater than the recommended taper angle. **Conclusion:** The preparation of porcelain-fused-to-metal performed by FKG Unpad clinical students did not reach the ideal taper angle. Dental students should receive hands-on clinical training to evaluate their tooth preparation performance and outcomes, in order to achieve high quality dental care for patients, using either conventional methods (extracted teeth) or digital methods (dental simulators, augmented reality).

KEYWORDS: porcelain-fused-to-metal crown restoration, taper angle, tooth preparation

Penilaian sudut taper pada preparasi mahkota porcelain-fused-to-metal *yang dilakukan oleh mahasiswa kedokteran gigi: Studi observasional*

ABSTRAK

Pendahuluan: *Restorasi tidak langsung, seperti mahkota dan jembatan tetap porcelain-fused-to-metal (PFM), memerlukan preparasi yang harus mengikuti prinsip preparasi gigi yang telah ditetapkan untuk mencapai keberhasilan restorasi. Salah satu prinsip preparasi yang perlu diperhatikan adalah sudut taper yang dihasilkan dari kemiringan dinding aksial. Untuk mencapai retensi maksimal, sudut taper yang direkomendasikan adalah 6°. Dalam praktik klinis, kesalahan preparasi masih sering ditemukan, misalnya reduksi berlebih (over-reduction) dan kesulitan dalam melakukan reduksi aksial gigi. Oleh karena itu, pendidikan pada tingkat klinis diperlukan untuk melatih kompetensi mahasiswa serta meningkatkan keterampilan mereka agar dapat mencapai hasil preparasi yang sesuai rekomendasi dan lebih presisi. Tujuan penelitian ini untuk menilai sudut taper pada preparasi mahkota porcelain-fused-to-metal (PFM) oleh mahasiswa kedokteran gigi.* ***Metode:*** *Penelitian ini dilakukan menggunakan studi observasional deskriptif dengan jumlah sampel 30 pasien di Departemen Prostodonsia Rumah Sakit Gigi dan Mulut Universitas Padjadjaran yang dirawat oleh mahasiswa klinik Fakultas Kedokteran Gigi Universitas Padjadjaran. Rahang pasien dipindai menggunakan pemindai intraoral digital, kemudian besar sudut taper diukur menggunakan CorelDRAW, dengan sudut taper ideal 6–10°. Data yang diperoleh dianalisis secara statistik menggunakan uji chi-square.* ***Hasil:*** *Rerata sudut taper yang terbentuk secara mesiodistal dan bukolingual berturut-turut adalah 25,0° ± 14,5° dan 14,9° ± 12,7°, yang lebih besar daripada nilai sudut taper yang direkomendasikan.* ***Simpulan:*** *Preparasi porcelain-fused-to-metal yang dilakukan oleh mahasiswa klinik tidak mencapai nilai sudut taper ideal. Mahasiswa kedokteran gigi direkomendasikan untuk dilatih melalui pengalaman klinis langsung guna mengevaluasi performa dan hasil preparasi gigi mereka, sehingga dapat mencapai kualitas perawatan gigi yang tinggi bagi pasien, baik dengan metode konvensional (gigi asli pasca-ekstraksi) maupun metode digital (simulator kedokteran gigi, augmented reality).*

KATA KUNCI: *restorasi mahkota porcelain-fused-to-metal, sudut taper, preparasi gigi.*

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INTRODUCTION

The teeth are an essential part of the human body and play a vital role in the masticatory system.[1] Tooth loss can significantly affect an individual's quality of life, as it disrupts mastication, speech, and facial esthetics.[2,3] Therefore, the replacement of missing teeth is required to restore oral function and appearance. One of the most common treatment options is the use of tooth-supported indirect restorations such as fixed single crowns and fixed dental prostheses (bridges). These restorations have long been used to rehabilitate oral function and esthetics, and their survival and complication profiles have been extensively evaluated in recent systematic reviews.[1,4,5]

Fixed dentures are permanent prostheses that cannot be removed by patients due to the application of cement on the tooth or root structure, whether on natural teeth or implant-supported structures.[6] Crowns and bridges can be made from various materials, such as porcelain-fused-to-metal (PFM), which consist of pontics, retainers, and connectors.[5,7,8] PFM crowns are widely used in dental practice, as they combine two materials with different properties, namely a strong metal substructure coated with porcelain to resemble the appearance of natural teeth.[9] The crown is then cemented onto the prepared supporting teeth using dental cement to achieve adequate retention and strength.[10]

PFM crown preparation is considered a non-conservative procedure as it requires a significant reduction of tooth structure so that porcelain can cover the darker-colored metal substructure.[9] The preparation steps involved in creating PFM restorations need to adhere to fundamental preparation principles to achieve good retention and esthetics to obtain successful restoration outcomes.[11] Generally, preparation principles should consider teeth structure preservation, retention and resistance, structural durability, margin design and integrity, total occlusal convergence (TOC), occlusocervical/incisocervical dimension, presence of undercut, occlusal reduction, and preservation of periodontal tissues.[9,12,13] Failure to follow these principles can lead to complications such as fracture of abutments, abutment loosening, soft tissue damage, and esthetic complications.[14]

Tapering is created on the axial wall of tooth preparation relative to the longitudinal axis of the tooth, aiming to provide space for the cementation of the prostheses on the supporting tooth. The taper angle is created by the opposing sides of the axial surface of the preparation.[15] Rosenstiel et al., recommend a taper angle of 6°.[16] Goodacre suggests that the ideal taper angle should range between 10—20°.[15] Naidoo et al., state that there are variations in ideal taper angles during axial wall reduction, ranging between 4-6°, 3-14°, 8-12°, and 10-20°.[17] This indicates a significant difference in taper angles between theoretical textbook values and those observed in clinical practice. Taper angles play a critical role in providing resistance form in fixed prosthesis.[18]

A proper taper design will result in a well-retentive fixed prosthesis. Retention refers to the force that prevents the dislodgement of the prosthesis, contributing to its stability and long term durability.[17] The convergence angle or taper of a tooth preparation plays a critical role in the retention of fixed prostheses. Several studies have demonstrated that smaller taper angles produce higher retention values, as the parallelism between opposing walls increases resistance to dislodgement.[10,19] However, excessively small taper angles may create mechanical undercuts or hinder proper seating of the restoration, thereby complicating clinical procedures.[10] Conversely, as the taper angle increases, the retentive strength tends to decrease due to the reduction in the surface area between the prepared tooth and the luting cement.[20,21] Despite this, a total occlusal convergence of approximately 6° (around 3° per axial wall) is generally considered clinically acceptable, offering a balance between adequate retention and ease of prosthesis placement.[10]

Dental education combines theoretical knowledge and dexterity training to deliver high quality dental care.[12] To develop the skills and competence of dental students at the Faculty of Dentistry in Universitas Padjadjaran (Fakultas Kedokteran Gigi Universitas Padjadjaran; FKG Unpad), students are required to perform PFM preparation on patients at Rumah Sakit Gigi dan Mulut Universitas Padjadjaran (Dental Hospital of Universitas Padjadjaran; RSGM Unpad).[22] Careful and precise tooth preparation is essential since teeth have non-regenerative tissues.[9] Proper PFM preparation based on fundamental principles is necessary to ensure that the teeth can receive restoration and restore the form and function of lost teeth.[10] Proper preparation is crucial to avoid preparation errors, such as inadequate tooth reduction leading to crown detachment, excessive reduction causing damage to the pulp, and iatrogenic damage to adjacent teeth.[11]

The novelty of this research lies in the application of technology in digital dentistry, such as digital intraoral scanners and 3D software to objectively measure the taper angle in tooth

preparations. Thus, this study aims to assess the taper angle of PFM crown preparations in premolars performed by dental students at FKG Unpad.

METHODS

This study was a descriptive observational study using primary data in the form of intraoral scans of preparations performed by dental students on patients. The population of this study was RSGM Unpad patients, with samples consisting of patients who underwent PFM crown preparation on premolar teeth, with the preparations performed by FKG Unpad dental students from the 2018-2021 batch. The exclusion criteria included teeth prepared for other purposes other than PFM crowns, teeth prepared other than premolars, and the contraindications for PFM preparation, such as teeth with untreated periodontal abnormalities, teeth with caries reaching the pulp, extensive caries, and teeth with a history of spontaneous pain. The sample size was determined based on non-probability sampling using the Malhotra method. The recommended sample size is at least 4-5 times the measured variables, resulting in a minimum sample size of 24-30 samples.[23]

The study was conducted from March to April 2023 at the Prosthodontics Clinic, RSGM Unpad, Sekeloa, Bandung City, West Java. The research began by providing verbal and written information about the study to the patients, then obtaining signed informed consent from both the patients and the dental students. The sampling tool used was the digital intraoral scanner (PRIMESCAN (R), Dentsply Sirona, Bensheim, Germany), and the Connect SW version 5.2.4 software (Dentsply Sirona, Bensheim, Germany) were used to scan the jaws and surrounding soft tissues, creating three-dimensional models. After scanning the patients' jaws, the files were sectioned mesiodistally and buccolingually using Autodesk Meshmixer version 3.5 software. Two-dimensional angle measurements were performed on the sectioned images using CorelDRAW X7 software, connecting the innermost point of the preparation margin and the largest contour point of the prepared tooth, with an extended line created to form the taper angle convergence point. The measured angles included axial angles consisting of mesial, distal, buccal, and lingual aspects, with lines positioned parallel to the longitudinal axis of the tooth, while the taper angles were measured in the mesiodistal and buccolingual planes (Fig. 1). The research findings underwent reliability and validity testing, with inter-observer measurement involving two observers. The collected data were recorded in Microsoft Excel, then analyzed using SPSS version 23 software, using the chi-square test to evaluate the taper angle preparation outcomes. This study obtained ethical clearance approval number 210/UN6.KEP/EC/2023.

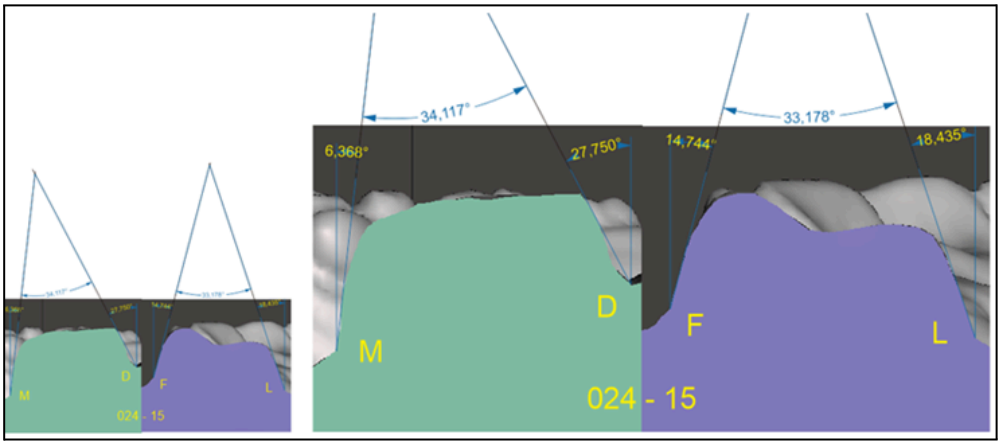

Figure 1. The measurement of the axial angle and taper angle using the CorelDRAW software

RESULTS

A total of 30 patients from RSGM Unpad met the inclusion criteria and were willing to participate in this study. The findings of this research are presented in the following tables.

Table 1. Distribution of patients in RSGM Unpad by gender

Gender	N	Percentage
Male	7	23.3%
Female	23	76.7%
Total	30	100.0%

Table 1 shows that patients who underwent PFM preparation on premolar teeth were predominantly female, accounting for 76.7%, while males accounted for 23.3%.

Table 2. Distribution of premolar teeth with PFM preparation according to jaw region

Jaw	N	Percentage
Maxilla	7	23.3%
Mandible	23	76.7%
Total	30	100.0%

Table 2 shows that the majority of premolar teeth with PFM preparation were located in the mandible (76.7%), whereas the maxilla accounting for 23.3%.

Table 3. Distribution of tooth loss on RSGM Unpad patients

Jaw	Missing tooth	N	Percentage
Maxilla	1st Premolar	4	13.3%
	2nd Premolar	2	6.7%
	1st Molar	1	3.3%
Mandible	1st Premolar	1	3.3%
	2nd Premolar	2	6.7%
	1st Molar	20	66.7%
Total		30	100.0%

Table 3 shows that tooth loss among patients receiving fixed dental prostheses at RSGM Unpad was most commonly observed in the first mandibular molars (66.7%). The lowest occurrence was observed in the first maxillary molars and first mandibular premolars (3.3% each).

Table 4. Average measurement results of axial angles and taper angles in PFM preparations at RSGM Unpad

Premolar tooth	N	Mesial angle	Distal angle	MD taper	Buccal angle	Lingual angle	BL angle
		Mean	Mean	Mean	Mean	Mean	Mean
Maxillary Right	5	8.27	16.59	24.86	0.89	10.12	11.01
Maxillary Left	2	22.33	13.95	36.28	-0.40	21.21	20.81
Mandibular Left	11	8.25	12.96	20.74	7.84	8.65	16.44
Mandibular Right	12	16.32	10.83	27.15	7.83	6.39	14.17
Total	30	12.42	12.78	25.03	6.13	8.83	14.92

Table 4 shows the average measurements of axial angles and taper angles in PFM preparations on premolar teeth. The average axial angle for the mesial side was 12.42°, for the distal side, 12.78°, for the buccal side, 6.13°, and for the lingual side, 8.83°. The average taper angles in the mesiodistal and buccolingual aspects were 25.03° and 14.92°, respectively.

Table 5. Ideal taper angle and the distribution of taper angles in RSGM Unpad patients mesiodistally

			MD taper category		Total
			Ideal	Non-ideal	
Premolar tooth region	Maxillary right	N	1	4	5
		% in region	20.0%	80.0%	100.0%
		% in MD taper category	33.3%	14.8%	16.7%
	Maxillary left	N	0	2	2
		% in region	0.0%	100.0%	100.0%
		% in MD taper category	0.0%	7.4%	6.7%
	Mandibular left	N	1	10	11
		% in region	9.1%	90.9%	100.0%
		% in MD taper category	33.3%	37.0%	36.7%
	Mandibular right	N	1	11	12
		% in region	8.3%	91.7%	100.0%
		% in MD taper category	33.3%	40.7%	40.0%
Total		N	3	27	30
		% in region	10.0%	90.0%	100.0%
		% in MD taper category	100.0%	100.0%	100.0%

Table 5 shows that among the premolar teeth that underwent PFM preparation mesiodistally, 3 cases (10.0%) had an ideal taper angle, while 27 cases (90.0%) had a non-ideal taper angle. The distribution of premolar teeth with ideal taper angles included 1 tooth in the right maxillary region, 1 tooth in the left mandibular region, and 1 tooth in the right mandibular region.

Table 6. Ideal taper angle and the distribution of taper angles in RSGM Unpad patients buccolingually

			BL taper category		Total
			Ideal	Non-ideal	
Premolar tooth region	Maxillary right	N	0	5	5
		% in region	0.0%	100.0%	100.0%
		% in BL taper category	0.0%	18.5%	16.7%
	Maxillary left	N	0	2	2
		% in region	0.0%	100.0%	100.0%
		% in BL taper category	0.0%	7.4%	6.7%
	Mandibular left	N	0	11	11
		% in region	0.0%	100.0%	100.0%
		% in BL taper category	0.0%	40.7%	36.7%
	Mandibular right	N	3	9	12
		% in region	25.0%	75.0%	100.0%
		% in BL taper category	100.0%	33.3%	40.0%
	Total	N	3	27	30
		% in region	10.0%	90.0%	100.0%
		% in BL taper category	100.0%	100.0%	100.0%

Table 6 shows that among the premolar teeth that underwent PFM preparation buccolingually, 3 cases (10.0%) had an ideal taper angle, while 27 cases (90.0%) had a non-ideal taper angle. The distribution of premolar teeth with ideal taper angles included 3 teeth in the right mandibular region.

Table 7. Ideal taper angle and the measured taper angle in RSGM Unpad patients

Variable	Ideal taper angle	Mean ± SD	Chi-Square	P-Value	Results
MD taper	6-10°	25.0° ± 14.5°	0.825	0.843	Not ideal
BL taper	6-10°	14.9° ± 12.7°	5	0.172	Not ideal

Significance level set at 0.05; standard deviation (SD)

Table 7 shows that the mesiodistal and buccolingual taper angles resulting from the preparations performed by dental students at FKG Unpad did not reach the recommended ideal values (6-10°).[9,10,12]

DISCUSSION

Patients at RSGM Unpad who were undergoing PFM crown treatment were predominantly female (Table 1). This aligns with previous studies showing that gender differences influence attitudes and behaviors towards maintaining dental and oral health, with female patients being more likely to visit dentists regularly for preventive care.[24–26] Additionally, the study was conducted on weekdays, which may have influenced the higher participation of stay-at-home mothers who could allocate time for dental visits.

PFM crown preparations were more commonly found in the mandibular region (Table 2). This is supported by a study conducted in Indonesia by Mangkat et al., which reported that tooth loss was more prevalent in the mandible (81.33%) compared to the maxilla (74.67%). Since the first permanent teeth to erupt are the mandibular first molars, they are more susceptible to dental caries due to their early eruption and prolonged exposure to the oral environment. Consequently, these teeth are among the most frequently affected by caries and extraction in children (Table 3).[27] Another study conducted by Heydari et al. reported that a lack of parental awareness regarding the eruption timing of the mandibular first permanent molars often leads parents to mistakenly believe that these teeth have successors. This misconception delays appropriate preventive or restorative intervention, contributing to higher rates of decay and tooth loss among children.[28]

The measured taper angles show higher values in the mesiodistal direction compared to the buccolingual direction (Table 4). The higher mesiodistal taper angles may be attributed to higher axial angles on the mesial and distal planes compared to those on the buccal and lingual planes. This aligns with Khanna et al., who reported that larger taper angle values are also found in the mesiodistal aspect (22.4°) compared to the buccolingual aspect (16.8°).[11]

The ideal taper angles achieved in the mesiodistal direction were more commonly found in the mandible than in the maxilla (Table 5), while the ideal taper angles achieved in the buccolingual direction were only found in the mandible (Table 6). The oral cavity provides a confined working space surrounded by adjacent hard and soft tissues, which presents a challenge for inexperienced dental students when performing intraoral preparations. Studies have reported that limited access, indirect vision, and hand–eye coordination difficulties are among the most common challenges faced by students during preclinical and clinical operative procedures.[29,30] Therefore, adequate illumination and proper isolation of the operating field from saliva using cotton rolls or a rubber dam are essential to achieve optimal visibility and effective moisture control during tooth preparation. Evidence from clinical trials and systematic reviews has demonstrated that the use of rubber dam isolation improves restoration quality and longevity compared to cotton roll isolation, primarily by providing superior moisture control and visibility.[31,32] Additionally, the speed of the handpiece also influences the preparation outcomes. The use of high-speed handpieces with appropriate burs is recommended as they are more efficient in the removal of tooth structure, enabling more controlled and efficient preparations with less pressure on the tooth. Furthermore, operators have better control and stability over the instruments.[33]

The preparation outcomes achieved by dental students at FKG Unpad did not reach the recommended ideal taper angles of 6-10° (Table 7). This is evidenced by the chi-square test results, which indicate that the classification of ideal and non-ideal taper angles used in this study is statistically valid. The results show that the majority of the examined teeth fall into the non-ideal group. In the study conducted by Deepak et al., common preparation errors included damage to gingival tissues due to subgingival margin placement, improper bur positioning or angulation, and over-preparation of the teeth.[34] Another study by Habib, S. R. reported that common preparation errors encountered by dental students were related to axial reduction and damage to adjacent teeth.[35] Naidoo et al., reported that over-tapered teeth preparation resulted due to the lack of clinical experience in dental students.[17] Clinical education trains dental students in eye-hand coordination and spatial reasoning, resulting in more precise and conservative preparations.[10]

This phenomenon can serve as a basis for curriculum development in dental education. According to research conducted by Gilmour et al., dental students' confidence levels in fixed prosthodontics are the lowest due to limited clinical preparation experience.[36] Therefore, it is recommended that dental students practice their PFM crown preparation skills by first engaging in preparation exercises on practice models, using either artificial teeth or post-extraction teeth. New innovations in dental education allow dental students to experience tooth preparation through digital dental simulators and augmented reality (AR) technology.[12,37]

The limitations of this study include limited sample size, necessitating further research on a larger scale. Additionally, this study only evaluated the taper angle of a single tooth, highlighting the need for further research to examine the alignment between the preparation outcomes of two abutment teeth for a three-unit bridge, considering the path of insertion and retention for PFM crowns. Further research is recommended to explore variations in taper angles among dental students, considering factors such as gender, dominant hand, and batch year of the operators. It is also suggested to investigate differences in taper angles resulting from the preparations performed between dental students, general practice dentists, prosthodontic residents, and prosthodontic specialists with varying levels of expertise and years of experience. It is hoped that this study can serve as a reference for curriculum developers in assessing the achievement indicators for the development of competence in dental students, enabling them to perform precise and accurate preparations for PFM crowns, leading to more favorable restorative outcomes.

CONCLUSION

The taper angles of the PFM preparations performed by dental students at FKG Unpad did not reach the recommended ideal taper angle at 6-10°. The average taper angles formed in the mesiodistal and buccolingual planes were 25.0° ± 14.5° and 14.9° ± 12.7°, respectively.

The implication of this study is that dental students require additional training in tooth preparation for fixed prosthesis, as failure to meet preparation principles, appropriate taper angles, may lead to prosthesis failure, including fabrication error, dislodgement of the prosthesis, and damage to the surrounding tissues. Hands-on clinical training is recommended to evaluate and improve students' tooth preparation performance, thereby supporting the delivery of high-quality dental care. Additional training may involve conventional methods (post-extraction teeth in dental mannequins/models) as well as digital approaches (dental simulators, AR), with final preparation outcomes evaluated using CAD tools to enhance accuracy and support dental education.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.
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