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Original Article

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A bibliometric analysis of the 100 most cited genioplasty articles (1950-2025)

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ABSTRACT

Aims: Genioplasty is a widely used surgical technique to correct chin deformities and improve facial harmony. Despite its clinical relevance, a systematic evaluation of influential studies and research trends in this field is lacking. This study aimed to identify and analyze the 100 most cited articles on genioplasty through bibliometric methods.

Methods: A title-specific search using the keyword "genioplasty" was conducted in the Web of Science Core Collection on July 25, 2025, covering the years 1950 to 2025. A total of 403 articles were retrieved and ranked by total citation count. After screening titles and abstracts, the 100 most cited articles with a primary focus on genioplasty were selected by two independent reviewers. Extracted data included publication year, journal name, total citations, average citations per year, authorship, study design, and primary topic. Descriptive statistics were used for analysis.

Results: Citation counts ranged from 13 to 86. Most articles were published after 2000, with a peak in the 2010s. The Journal of Oral and Maxillofacial Surgery (n=20) and Plastic and Reconstructive Surgery (n=13) were the most represented journals. The most common topics were surgical technique (n=45) and outcome evaluation (n=34). Retrospective (n=35) and prospective (n=25) cohort studies dominated, while randomized controlled trials were rare (n=3).

Conclusion: This bibliometric analysis reveals the leading themes, study types, and journals in genioplasty research, offering valuable insight for future investigations in facial skeletal surgery.

Keywords: Genioplasty, chin, maxillofacial surgery, bibliometrics

INTRODUCTION

Facial aesthetics is achieved through a harmonious, proportional, and symmetrical relationship between the facial skeleton and the surrounding soft tissues. In recent years, the growing aesthetic concerns and expectations of individuals have stimulated the development of both functional and cosmetic interventions targeting the facial region.[1] The prominence of the chin plays a critical role in the aesthetic assessment of the facial profile and significantly influences the overall balance and symmetry of the face. In aesthetic perception, the chin structure has historically and culturally been regarded as a symbol of strength and confidence, and is considered one of the facial features that provide insight into an individual's character.[2]

During the clinical evaluation process, measurements related to the chin tip provide critical guidance in determining the appropriate treatment plan. Various techniques have been described in the literature, and with proper patient selection, these methods offer several aesthetic and functional advantages.[3] Genioplasty is one of the commonly used surgical approaches for correcting volume deficiencies and asymmetries of the chin, as well as for masking unaesthetic mandibular relationships.[4]

The increasing number of published articles presents a significant challenge for both researchers and clinicians in identifying studies with the highest quality and greatest clinical impact.[5] Therefore, systematically evaluating the existing literature and providing readers with comprehensive insights through bibliometric analyses has become increasingly important.[6] Bibliometric analyses assess the citation performance, impact, and contributions of scientific publications within a specific field, enabling the identification of influential studies and thematic trends. Analyzing high-impact publications is crucial for understanding developments in the fields of surgery and orthodontics and for identifying pivotal studies that guide future research.[7]

In this study, we aimed to conduct the first comprehensive bibliometric analysis of the literature on genioplasty by evaluating the quality and characteristics of the 100 most cited articles and identifying emerging research trends in the field.

METHODS

A bibliometric analysis was conducted to identify the 100 most cited articles on the topic of genioplasty. On July 25, 2025, the keyword "genioplasty" was used in a title-specific search

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within the Web of Science Core Collection database (Clarivate Analytics, Philadelphia, PA, USA), which is recognized for its comprehensive indexing of high-impact scientific literature. The search was performed without limitations on language or study type and covered all available publication years, from 1950 to 2025.

A total of 403 articles were initially retrieved. These were ranked in descending order based on the total number of citations. To ensure that only relevant articles focusing primarily on genioplasty were included, two independent reviewers (author 1 and 2) screened all titles and abstracts. Publications in which genioplasty was mentioned only peripherally or as an adjunctive procedure were excluded. Any discrepancies during this selection process were resolved through discussion and, when necessary, by consulting a third reviewer (author 3).

The final list comprised the 100 most cited articles directly related to genioplasty. Full texts of the selected articles were accessed, and data were independently extracted by two authors using a standardized Microsoft Excel spreadsheet (version 14.7.7; Microsoft Corp., Redmond, WA, USA). The following variables were recorded: article title, list of authors, year of publication, source journal, total number of citations, average number of citations per year, study design, and main research topic. Categorical data such as study design and thematic focus were classified using predefined criteria based on existing bibliometric literature. All extracted data were cross-checked for consistency and accuracy.

As this study was based solely on published data from the scientific literature, ethical approval was not required. All procedures were carried out in accordance with the ethical rules and the principles.

RESULTS

A comprehensive search conducted in the Web of Science database using the keyword related to genioplasty yielded a total of 403 articles. These articles were ranked according to their citation counts, and the top 100 most cited articles were selected. The included articles and their corresponding citation counts are provided as a supplementary file. The total number of citations among the selected articles ranged from 13 to 86. The most cited article was titled "Vulnerability of the inferior alveolar nerve and mental nerve during genioplasty: an anatomic study", published by Hwang et al.,[8] which received a total of 86 citations and emerged as the most influential publication.

Among the top 100 analyzed articles, the Journal of Oral and Maxillofacial Surgery was the most contributive journal, with 20 publications. This was followed by Plastic and Reconstructive Surgery with 13 articles, and the International Journal of Oral and Maxillofacial Surgery with 10 articles. This finding reflects the significant contribution of these journals to the scientific output in the field of genioplasty (**Table 1**).

When the distribution of publications by decade was examined, the highest number of articles was published in the 2010s, with a total of 33 publications. This was followed by 26 articles in the 2000s and 21 articles in the 1980s. In the 1990s, 13 articles were published, whereas only 7 articles have been published so far in the 2020s (**Table 2**).

When the contribution of countries and their citation counts were evaluated, South Korea had the highest total number of citations, with 8 publications receiving a total of 280 citations (**Table 3**).

Table 1. Journals with the highest number of publications among the top 100 most cited genioplasty articles

Journal	Number of articles
Journal of Oral and Maxillofacial Surgery	20
Plastic and Reconstructive Surgery	13
International Journal of Oral and Maxillofacial Surgery	10
Journal of Cranio-Maxillofacial Surgery	6
Journal of Craniofacial Surgery	5
Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics	5
British Journal Of Oral & Maxillofacial Surgery	5
Aesthetic Plastic Surgery	5
Journal Of Oral Surgery	4
Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontology	4
Clinics In Plastic Surgery	3
American Journal of Orthodontics and Dentofacial Orthopedics	3
Jama Facial Plastic Surgery	3
Scientific Reports	2
Scandinavian Journal of Plastic and Reconstructive Surgery and Hand Surgery	1
International Journal of Oral Surgery	1
Annals of Plastic Surgery	1
Facial Plastic Surgery	1
Plos One	1
Open Dentistry Journal	1
Laryngoscope	1
Journal of Maxillofacial & Oral Surgery	1
Journal of Stomatology Oral and Maxillofacial Surgery	1
Journal of Plastic Reconstructive and Aesthetic Surgery	1
Facial Plastic Surgery Clinics of North America	1
British Journal of Plastic Surgery	1

Table 2. Distribution of the top-cited genioplasty articles by decade of publication

Decade	Number of articles
1980's	21
1990's	13
2000's	26
2010's	33
2020's	7

Table 3. Top contributing countries in genioplasty research based on citation count and number of articles

Country	Total citations	Number of articles
South Korea	280	8
USA	240	8
Italy	164	5
China	157	6
Germany	90	4

An analysis of the topic distribution of the top 100 most cited genioplasty articles revealed that studies focusing on surgical techniques were the most prevalent, accounting for 45 publications. These were followed by 34 studies centered on outcome evaluation. Other notable topics included prognosis and risk factors (n=7) and anesthesia/analgesia techniques (n=4). The remaining articles addressed less represented themes such as anatomy (n=4), non-operative approaches (n=2), as well as topics related to pathology, psychology, and public health (**Figure 1**).

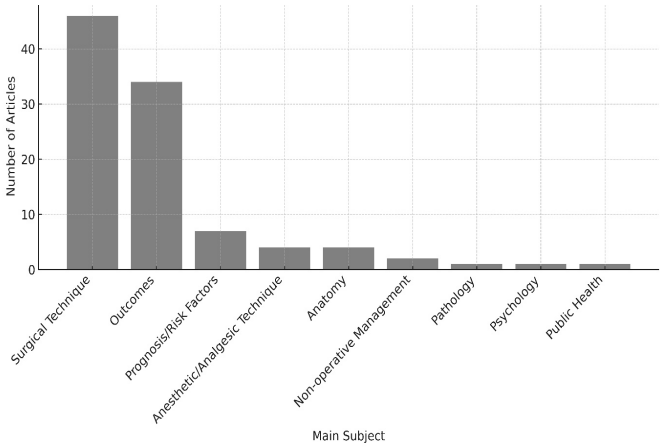

Figure 1. Distribution of the main subjects addressed in the top 100 most cited articles on genioplasty

When the study designs were examined, retrospective cohort studies were the most commonly used, with 35 articles, followed by prospective cohort studies (n=25) and case series (n=20). Other, less frequently employed designs included case reports (n=8), reviews (n=5), expert opinions (n=4), and randomized controlled trials (n=3) (**Figure 2**).

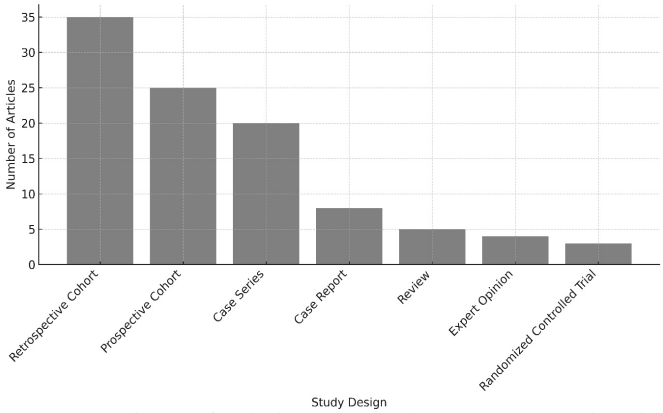

Figure 2. Distribution of study designs among the top 100 most cited articles on genioplasty

DISCUSSION

This bibliometric analysis systematically evaluated the scientific output in the field of genioplasty, revealing key trends, high-impact studies, and methodological gaps. Examination of the most frequently cited articles showed that their primary themes focused on the technical aspects of genioplasty, soft and hard tissue outcomes, complications, and its relationship with adjunctive surgical procedures. For instance, the most highly cited article defined surgical safety margins against potential nerve injuries by analyzing the anatomical course of the mandibular nerves during genioplasty.[8] This study specifically recommends performing the osteotomy at least ~4-5 mm below the inferior border of the mental foramen and highlights that, in cases of micrognathia, the mental foramen may be located closer to the inferior margin of the mandible. Indeed, a recent study utilizing modern imaging techniques confirmed the classic "5 mm rule" and even suggested that in certain skeletal anatomies, a distance of 7-9 mm may be necessary to eliminate the risk of nerve injury entirely.[9]

A significant portion of the highly cited publications focus on changes in the soft tissue profile. For instance, the pioneering studies conducted by Gallagher et al.[10] in the 1980s quantitatively demonstrated positional changes in the chin and lips following genioplasty. In Polido's[11] retrospective analyses, patients who underwent advancement genioplasty showed an average of ~0.8-0.9 mm of soft tissue advancement for every 1 mm of bony advancement. This finding has been confirmed by numerous subsequent studies and plays a critical role in helping surgeons manage patients' aesthetic expectations. Indeed, a large case series published in 1991 demonstrated that in patients who underwent an average of 11.7 mm of advancement genioplasty, 76% of the bony projection was maintained (24% resorption), and the soft tissue followed the bony movement by approximately 88%.

In light of these studies, it has become evident that bony movement in chin aesthetics is largely predictable in terms of external projection; however, in cases of excessive advancement, soft tissue may act as a limiting factor. For example, Rosen's[12] work-often referred to as the "aesthetic guidelines for genioplasty"-emphasized that excessive chin advancement could disrupt profile balance by evaluating the position of the lower lip. Rosen advised that "the chin should not be advanced beyond the plane of a retruded lower lip", providing a guideline to help prevent a disproportionate appearance.

The issues of bone stability and resorption also occupy a significant place in the literature. Particularly due to concerns about long-term bone resorption following large advancements, this topic was extensively investigated during the late 1980s and 1990s. In this context, the pedicled genioplasty technique-maintaining soft tissue attachments-was developed, and Bell introduced the "broad-based pedicled genioplasty" approach. The primary objective of this technique is to preserve periosteal and muscular attachments to maintain vascular supply and thereby reduce bone resorption. Indeed, Vedtofte et al.[13] compared 29 cases treated with pedicled versus free (non-pedicled) bone grafts and reported that preserving the soft tissue pedicle resulted in significantly less bone resorption (notably lower in the pedicled group, $p<0.01$) and a reduced risk of postoperative infection. This study demonstrated that pedicled genioplasty provides more predictable long-term outcomes by reducing both bone loss and infection rates. As a result, in modern genioplasty cases requiring significant advancement, it is recommended to preserve the soft tissue pedicle whenever possible or to enhance stability through additional fixation measures.

Complications and neurosensory effects represent another key focus among the most highly cited publications. Numerous studies have consistently reported that the most common complication following genioplasty is temporary paresthesiaof the lower lip and teeth.[14] Genioplasty, due to its anatomical location along the inferior border of the mandible,

has the potential to exert traumatic effects on the inferior alveolar nerve and mental nerve. One of the highly cited studies by Lindquist and Obeid[15] reported altered sensation in the mental nerve region in 10% of patients who underwent isolated genioplasty, whereas this rate increased to 28.5% in objective tests when genioplasty was combined with bilateral sagittal split osteotomy (BSSO).

The bibliometric analysis of the genioplasty literature highlights historical trends and influential studies within the field of jaw surgery. In our review covering the period from 1950 to 2025, it was observed that the majority of the top 100 most cited articles were published from the 1980s onward. Notably, there has been a marked increase in the number of publications since the 2000s, which parallels the overall growth of the orthognathic surgery literature.[16]

An analysis of journal distribution revealed that the majority of publications appeared in leading journals within the field of maxillofacial surgery. The journal with the highest number of articles was the Journal of Oral and Maxillofacial Surgery (JOMS), the official publication of the American Association of Oral and Maxillofacial Surgeons. Indeed, a bibliometric study on orthognathic surgery also reported that JOMS ranked first in terms of both the number of articles and total citation frequency.[17] Interestingly, a significant portion of the articles in our list were also published in plastic surgery journals. In particular, plastic and reconstructive surgery (PRS) and aesthetic plastic surgery have featured studies addressing chin aesthetics from the perspective of plastic surgery. This highlights the dual disciplinary relevance of genioplasty; it holds a strong position in the oral and maxillofacial surgery literature as part of orthognathic and functional surgery, while also occupying an important role in the plastic surgery literature as a component of facial aesthetics.

The author analysis of the top 100 most cited articles reveals the leading contributors and collaborative patterns in the field. Gallagher et al.[10] who introduced several innovative genioplasty techniques during the 1980s, stands out as the most prolific author, with multiple studies included in our list. Bell's groundbreaking work-such as the broad-based pedicled genioplasty technique, profile modifications combined with maxillary surgery, and soft tissue responses-has been widely cited in the literature and has laid the foundation for subsequent research.

In terms of country distribution, while the United States has historically maintained a leading position, it is noteworthy that since the 2000s, countries such as South Korea, China, Japan, Brazil, and Turkey have also produced highly cited studies. Although it has been reported that approximately 70% of the most influential publications in orthognathic surgery originate from North America, the number and impact of contributions from Asia and Europe have been steadily increasing.[18] In particular, studies originating from South Korea, China, and Taiwan have shown a notable increase in both volume and citation impact over the past 10 to 15 years.[17]

The findings regarding the study types of the articles we analyzed reflect the characteristics of the maxillofacial surgery literature. The vast majority of the top 100 most cited articles consist of original research studies. A substantial portion of these original research articles are retrospective cohort studies or case series. Indeed, it has been reported that approximately 54% of the most frequently cited studies in the field of orthognathic surgery are retrospective cohorts or case series, while only a small proportion are prospective or randomized studies.[18]

Genioplasty is increasingly recognized not only as an aesthetic intervention but also as a functional procedure, particularly when combined with genioglossus advancement in the management of obstructive sleep apnea. Recent long-term follow-up studies have shown that this combined approach can significantly improve airway patency, reduce apnea-hypopnea indices, and contribute to enhanced quality of life in affected patients. Moreover, the multidisciplinary perspective highlights that genioplasty should be considered in the broader context of airway, esthetic, and functional outcomes, rather than being limited to cosmetic correction of the chin profile.[19]

Similarly, in our list, randomized controlled trials (RCTs) are virtually absent. Although a few prospective studies with clinical trial characteristics are present, large-scale RCTs remain rare in this field due to ethical and practical challenges. Instead, long-term case series, multicenter retrospective analyses, and meta-analyses have received more citations. Additionally, review articles and technical overviews represent only a small portion of the included publications.

This bibliometric review provides a comprehensive evaluation of the 100 most influential articles on genioplasty published from 1950 to the present. Our discussion findings shed light on how research trends in the field of genioplasty have evolved over time. While early studies primarily focused on the description of fundamental surgical techniques and soft tissue balancing, subsequent publications emphasized reducing complications and improving functional outcomes. In more recent years, there has been a growing focus on digital planning, three-dimensional imaging, and topics such as patient satisfaction and quality of life.

Our bibliometric analysis also highlights the multidisciplinary nature of genioplasty research. In addition to oral and maxillofacial surgeons, specialists from diverse fields -such as plastic and reconstructive surgery, otolaryngology and sleep medicine, and orthodontics- have contributed significantly to this body of literature. This reflects the fact that jaw surgery encompasses multiple dimensions, including aesthetics, function, phonation, and respiration. Indeed, when examining the topics of the most highly cited publications, a wide spectrum is evident-ranging from aesthetic profile analysis, stability and orthodontic planning, to airway patency, protection of sensory nerve function, and biomaterial applications. The distribution of countries and research centers further confirms this multidimensionality, with a broad geographic diversity spanning from North America and Europe to Asia and South America.

CONCLUSION

As a result, the genioplasty literature represents a rich field encompassing both the longstanding surgical experience of the past and contemporary innovations. Such bibliometric studies provide researchers with a comprehensive platform to identify the strengths and gaps within the literature, thereby contributing to shaping future directions in the field.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study does not involve human participants, animal subjects, or personal data. Therefore, ethics committee approval was not required.

Informed Consent

Since this research is a bibliometric study, it did not require informed consent.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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Original Article

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Evaluation of tooth wear and gingival recession in individuals with obsessive-compulsive symptoms: a clinical study

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ABSTRACT

Aims: This study aimed to evaluate tooth wear and gingival recession in individuals presenting with obsessive-compulsive disorder (OCD) symptoms and to investigate potential associations with obsessive-compulsive symptom severity, toothbrushing habits, and demographic characteristics.

Methods: A cross-sectional design was applied, including 143 participants aged 16-70 years with at least 20 natural teeth who met the inclusion criteria. All participants completed a demographic information form, an oral hygiene questionnaire, and the Obsessive-Compulsive Inventory-Revised (OCI-R). Clinical examination assessed tooth wear using the Bartlett Tooth Wear Index and gingival recession using the Miller Classification. Data were analyzed with SPSS 27.0. Group comparisons were performed with the Mann-Whitney U test, and correlations were examined with Spearman's correlation and regression analysis.

Results: Of the participants, 18.9% scored OCI-R ≥21, indicating higher obsessive-compulsive symptoms. Females brushed more frequently than males, and younger participants brushed more often than older individuals ($p<0.05$). Gingival recession scores did not differ significantly between high and low OCI-R groups ($p>0.05$). However, occlusal enamel (OE3), occlusal dentin (OD2), and cervical (C3) wear scores were significantly higher in the high OCI-R group ($p<0.05$). Weak-to-moderate correlations were observed between the OCI-R ordering subscale and selected occlusal wear parameters. Overall, no strong associations were found between total OCI-R scores and tooth wear or gingival recession.

Conclusion: The findings suggest that while gingival recession may not increase in individuals with obsessive-compulsive symptoms, certain occlusal wear patterns may be more prevalent. Obsessive behaviors such as excessive toothbrushing, bruxism, and ordering compulsions may play a role in these outcomes. Dental practitioners should consider these behavioral factors when providing preventive strategies and oral hygiene education. A multidisciplinary approach is recommended to optimize the oral health management of individuals with obsessive-compulsive tendencies.

Keywords: Obsessive-compulsive disorder, tooth wear, gingival recession

INTRODUCTION

Obsessive-compulsive disorder (OCD) is a disorder closely associated with anxiety and depression, with distinct perceptual and behavioral symptoms.[1] It is a chronic, anxiety-based psychiatric disorder characterized by recurrent thoughts (obsessions) that the individual cannot control and repetitive behaviors (compulsions) aimed at neutralizing these thoughts.[2] The most common obsessions include fear of contamination, orderliness, and doubt, while compulsions include excessive hand washing, repeated checking, or performing specific rituals.[3] According to the World Health Organization (WHO), OCD is one of the ten mental illnesses that most affect quality of life.[4] It occurs in approximately 2-3% of the population, typically beginning during adolescence and potentially persisting throughout life.[5] This disorder is often comorbid with other psychiatric conditions such as major depression, generalized anxiety disorder, tic disorders, and body dysmorphic disorder.[6]

Obsessions with themes of cleanliness, order, symmetry, and control can significantly affect the daily habits of individuals with OCD. In this context, oral hygiene practices may also become excessive as part of compulsive cleaning behaviors. The literature reports that the frequency of tooth brushing among OCD patients is higher compared to healthy individuals, while the brushing duration does not differ significantly.[7] Another study strongly demonstrates a clinically significant and direct relationship between OCD and tooth brushing behavior.[8] Individuals with OCD spend longer amounts of time on most routine daily activities compared to others.[9] Frequent and forceful tooth brushing may predispose to hard tissue wear and gingival recession in the long term, while in the short term it may reduce plaque accumulation and lower the incidence of caries. However, obsessive cleaning behaviors may also lead to excessive and inappropriate use of oral care products. Considering all these factors, it is thought that

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the oral hygiene habits of individuals with OCD have both protective and harmful potential, thus requiring special evaluation and guidance in terms of oral health.

Although the frequency and duration of tooth brushing are of fundamental importance in maintaining oral hygiene, the intensity and manner of these habits can cause mechanical trauma to oral tissues. Particularly, brushing performed excessively and without control may result in enamel and dentin loss in the cervical region, increasing non-carious tooth wear.[10] The wear index defined by Bartlett et al.[11] provides an objective assessment of such hard tissue losses. In addition, inappropriate brushing techniques can also cause gingival recession. This condition is clinically staged according to the Miller classification.[12] Compulsive behaviors related to cleanliness and hygiene are frequently observed in individuals with OCD, and it has been reported that these individuals may have a tendency to brush their teeth more than once a day, for prolonged durations, and with excessive force. Although this may improve plaque control, it can predispose to undesirable outcomes such as tooth wear, gingival recession, and dentin hypersensitivity.[13,14] Therefore, oral hygiene habits associated with psychiatric conditions such as OCD should be evaluated not only in terms of frequency, but also in relation to the method, duration, and psychological origins of these practices.[15] The aim of this study is to evaluate gingival recession and tooth wear findings in individuals with OCD symptoms and to investigate possible associations between these findings and the severity of obsessive-compulsive symptoms, tooth brushing habits, and demographic characteristics. The study has two null hypotheses:

- There is no difference in the amount of gingival recession between individuals with OCD symptoms and healthy individuals.
- There is no difference in tooth wear scores between individuals with OCD symptoms and healthy individuals.

METHODS

This study was designed as a cross-sectional clinical research study and was conducted at the Department of Restorative Dentistry, Faculty of Dentistry, İnönü University, between June and August 2025. All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki.

Power Analysis

The sample size of the study was calculated using G*power 3.1 software to evaluate the difference between two independent groups. With an effect size of Cohen's d=0.48, a significance level of α=0.05, and a statistical power (1-β)=0.80, a total of 140 participants (70 per group) were required. Under these parameters, the actual power of the study was calculated as 80.5%.

Inclusion Criteria

Individuals aged between 16 and 70 years, who could read and understand Turkish, and who had given written informed consent were included in the study. Participants were required to have at least 20 sound and clinically examinable natural teeth, to be free of fixed or removable prostheses, and to have no maxillary or mandibular tooth loss at a level that would hinder assessment. In addition, participants had to be capable of maintaining self-care independently and had to have completed the Obsessive-Compulsive Inventory-Revised (OCI-R), demographic data form, and oral hygiene habits questionnaire fully. Participants were not undergoing active treatment for any systemic or psychiatric illness and were not on regular medication. Only individuals who met the intraoral conditions for the application of the Exact Tooth Wear Index and the Miller classification of gingival recession during clinical examination were included.

Exclusion Criteria

Individuals who used regular medication or were under active medical treatment due to systemic or psychiatric illness were excluded. Those using fixed or removable prostheses, those with fewer than 20 natural and clinically examinable teeth, and those with structural anomalies of the jaw or facial region were also excluded. Additionally, individuals with extensive tooth loss hindering evaluation, severe periodontal disease, untreated active caries, or oral infections were not included. Participants who left questionnaires incomplete or refused clinical examination were also excluded from the analysis.

Tests Used in the Study

Obsessive-Compulsive Inventory-Revised (OCI-R): The OCI-R is a self-report instrument developed to assess the severity and prevalence of obsessive-compulsive disorder symptoms. Developed by Foa et al.,[16] the inventory consists of 18 items rated on a 5-point Likert Scale (0=not at all, 4=extremely). The scale comprises six subscales: washing, checking, ordering, obsessing, hoarding, and mental neutralizing. Each subscale consists of 3 items, and both subscale scores and a total score can be calculated. Higher scores indicate increased severity of obsessive-compulsive symptoms. The OCI-R is widely used both in clinical diagnosis and research, with strong validity and reliability. A Turkish validity and reliability study has been conducted and cultural adaptation confirmed.[17]

Miller classification of gingival recession: The Miller Classification of Gingival Recession is a clinical classification system developed to evaluate the extent and severity of gingival recessions.[18] This system categorizes recession from class I to class IV based on criteria such as the width and height of recession, condition of surrounding tissues, and the position of the mucogingival junction.

- **Class I:** Gingival recession limited to the cemento-enamel junction (CEJ), with no papilla loss; does not extend beyond the mucogingival junction.
- **Class II:** Recession extends beyond the mucogingival junction but without papilla or interproximal bone loss.
- **Class III:** Recession extending beyond the mucogingival junction with mild-to-moderate papilla or interproximal bone loss.
- **Class IV:** Advanced papilla and bone loss with recession evident in both horizontal and vertical dimensions.

The Miller classification allows systematic evaluation of soft tissue loss in periodontal tissues and is widely used for treatment planning and research.

Exact Tooth Wear Index (ETI): Following the Tooth Wear Index (TWI) developed by Smith and Knight[19] in 1984, Bartlett et al.[11] developed the ETI to provide a more detailed description of enamel-level tooth wear. This index evaluates

enamel tissue with 5 scores, dentin with 6 scores, and the cervical tooth region with 4 scores.

Demographic and Dental Health Questionnaire: Behavioral aspects such as daily tooth brushing frequency, brushing duration, sense of control during brushing, repetitive behaviors, and use of oral care products were assessed with open-ended and multiple-choice questions. Subjective evaluations of symptoms such as perceived oral discomfort, gingival bleeding, sensitivity, and esthetic concerns were also included.

Procedure

Prior to participation, individuals who met the eligibility criteria were informed in detail about the purpose, process, and voluntary nature of the study, and written informed consent was obtained from each participant. Following consent, participants completed the Demographic and Dental Health Questionnaire and the OCI-R form under the supervision of a psychologist. After completing the questionnaires, participants underwent intraoral clinical examination, during which tooth wear was assessed using the ETI. In the same session, gingival recession was recorded based on the Miller Classification. All measurements were performed by two dentists under standardized lighting conditions and in accordance with the clinical examination protocol.

Calibration

The indices were recorded by two dentist researchers (FÖ and RÇ). To ensure calibration between researchers, they underwent a period of theoretical training with practical exercises conducted on dental students. The training involved both examiners recording the index independently on the same subjects, discussing the results, and then re-examining several subjects to compare outcomes again. Both examiners scored the same conditions, compared their results, and discussed their experiences. This process continued across different subjects until both examiners consistently assigned the same scores for each surface, achieving at least 90% agreement across the full dentition.

Statistical Analysis

All data analyses were performed using SPSS Statistics for Windows, Version 27.0 (IBM Corp., Armonk, NY, USA). The distribution of groups was assessed using the Kolmogorov-Smirnov test. For independent groups not showing normal distribution, the Mann-Whitney U test was applied. Spearman's rho correlation analysis was used to examine relationships between variables. Linear regression analysis was conducted to evaluate the predictors of tooth wear scores. Statistical significance was set at $p<0.05$.

RESULTS

A total of 143 individuals, including 61 males and 82 females, participated in the study.

Statistical analyses revealed that females brushed their teeth more frequently than males (r=0.18, p=0.032). In the age-based evaluation, daily tooth brushing frequency was higher in the group under 35 years of age (r=0.19, p=0.02). Gingival recession was greater in individuals aged 35 years and above. Gingival recession in teeth M1 and M3 was significantly higher (r=0.32, p<0.001; r=0.34, p<0.001) (**Table 1**).

Table 1. The gender, age, DTBF, TBD, and OCI-R questionnaire scores of the participants in the study

	Male (n=61)	Female (n=82)	Average (n=143)
Age	33.05 (1.64)	32.85 (1.20)	32.94 (11.65)
DTBF	1.49 (0.08)^{A}	1.76 (0.08)^{B}	1.64 (0.7)
TBD	2.25 (0.14)	2.09 (0.12)	2.13 (1.1)
OCI-R	13.92 (0.92)	13.89 (0.98)	13.9 (8.15)
	Under 35 (n=61)	**35 years and over (n=82)**	
Age	24.46 (0.57)^{A}	44.33 (0.96)^{B}	32.94 (11.65)
DTBF	1.74 (0.08)^{A}	1.51 (0.09)^{B}	1.64 (0.7)
TBD	2.06 (0.12)	2.28 (0.14)	2.13 (1.1)
OCI-R	13.52 (0.92)	14.41 (1.02)	13.9 (8.15)

Letters indicate significant differences within the same row; values sharing a letter do not differ. DTBF: Daily tooth brushing frequency, TBD: Tooth brushing duration, OCI-R: Obsessive-Compulsive Inventory-Revised, r: Mann-Whitney's effect size

In the grouping of OCI-R and its subscales according to the OCI-R threshold score of 21, as expected, the scores of the groups showing OCI-R symptoms were significantly higher. Among the subscales, washing (OCI-R ≥21) was the group with the highest score (**Table 2**).

Table 2. Comparison of OCI-R subgroups based on the OCI-R threshold score

	Under 21 (n=116)	21 and over (n=27)	
OCI-R	8.7 (0.51)^{A}	22.48 (0.60)^{B}	r=83. p<0.001
Washing	1.84 (0.11)^{A}	4.19 (0.15)^{B}	r=0.7. p<0.001
Checking	1.63 (0.1)^{A}	4.13 (0.14)^{B}	r=0.78. p<0.001
Ordering	1.6 (0.12)^{A}	4.09 (0.18)^{B}	r=0.7. p<0.001
Obsessing	0.85 (0.08)^{A}	2.59 (0.15)^{B}	r=0.67. p<0.001
Hoarding	1.09 (0.1)^{A}	3.28 (0.21)^{B}	r=0.62. p<0.001
Mental neutralizing	1.83 (0.1)^{A}	4.13 (0.14)^{B}	r=0.73. p<0.001

Letters indicate significant differences within the same row; values sharing a letter do not differ. OCI-R: Obsessive-Compulsive Inventory-Revised, r: Mann-Whitney's effect size, p: Significance value

In the evaluations, age scores were evenly distributed in both groups (p>0.05). The number and duration of daily tooth brushing were similar in both groups. Gingival recession was also similar between the two groups, although it was higher in the group with scores below 21. Advanced tooth wear scores of 2 and 3, indicating more severe wear on occlusal and cervical surfaces, were higher in the group showing OCI-R symptoms (**Table 3**). Accordingly, OM3 (r=0.28, p=0.031), S3 (r=0.17, p=0.036), OD2 (r=0.20, p=0.013), and PD2 (r=0.20, p=0.013) tooth wear scores were significantly higher, and the differences were statistically significant. On the other hand, BM3 (r=0.18, p=0.31) and PD1 (r=0.25, p=0.003) scores were higher in the healthy group, with statistically significant differences (**Table 3**). According to the correlation analysis, the OCI-R ordering subscale score showed weak to moderate negative correlations with OM1 and OD0 wear scores, and positive correlations with OM3, OD1, and OD2 wear scores. However, the overall variance explained by the regression models was low, indicating that the ordering subscale had a limited predictive effect on wear scores (**Table 4**).

DISCUSSION

In this study, the effects of OCD symptoms on gingival recession and tooth wear were evaluated in 143 patients

Table 3. Comparison of age, DTBF, TBD, OCD, Miller gingival recession, and tooth wear scores according to the OCI-R threshold score of individuals participating in the study

Groups	Under 21	21 and over	Groups	Under 21	21 and over
Age	33.21 (1.23)	32.48 (1.62)	.	.	.
DTBF	1.63 (0.08)	1.67 (0.10)	.	.	.
TBD	2.17 (0.11)	2.13 (0.17)	.	.	.
M1	5.79 (0.56)	4.63 (0.62)	.	.	.
M2	2.28 (0.36)	1.48 (0.19)	.	.	.
M3	0.27 (0.09)	0.11 (0.04)	.	.	.
M4	0.02 (0.02)	0 (0)	.	.	.
OE0	0 (0)	0 (0)	OD0	13.6 (0.71)	12.44 (1.08)
OE1	2.88 (0.55)	2.24 (0.63)	OD1	10.75 (0.58)	10.63 (0.72)
OE2	15.3 (0.69)	13.2 (0.99)	OD2	1.11 (0.22)[A]	2.11 (0.42)[B]
OE3	6.61 (0.63)[A]	9.41 (0.94)[B]	OD3	0.05 (0.03)	0.09 (0.06)
OE4	0.7 (0.36)	0.8 (0.35)	OD4	0 (0)	0 (0)
OR	0.69 (0.12)	0.78 (0.16)	OD5	0.01 (0)	0 (0)
BE0	0 (0)	0 (0)	BD0	25.14 (0.34)	25.7 (0.41)
BE1	22.73 (0.72)	22.41 (1.13)	BD1	0.58 (0.13)	0.46 (0.14)
BE2	2.65 (0.48)	3.48 (0.81)	BD2	0.39 (0.09)	0.28 (0.10)
BE3	0.75 (0.27)[A]	0.37 (0.26)[B]	BD3	0.1 (0.04)	0.11 (0.04)
BE4	0.01 (0.01)	0 (0)	BD4	0 (0)	0 (0)
BR	0.14 (0.05)	0.09 (0.06)	BD5	0.01 (0)	0 (0)
C0	3.69 (0.75)	4.83 (0.94)	.	.	.
C1	17.95 (0.71)	16.63 (0.77)	.	.	.
C2	4.42 (0.48)	4.57 (0.61)	.	.	.
C3	0.13 (0.04)[A]	0.15 (0.10)[B]	.	.	.
CR	0.17 (0.09)	0.04 (0.03)	.	.	.
PE0	0 (0)	0 (0)	PD0	25.36 (0.33)	25.89 (0.34)
PE1	21.26 (0.60)	22.24 (0.56)	PD1	0.52 (0.08)[A]	0.22 (0.07)[B]
PE2	3.85 (0.33)	3.52 (0.39)	PD2	0.19 (0.06)[A]	0.02 (0.02)[B]
PE3	0.85 (0.22)	0.37 (0.13)	PD3	0.05 (0.03)	0 (0)
PE4	0.2 (0.12)	0.06 (0.06)	PD4	0 (0)	0 (0)
PR	0.18 (0.06)	0.17 (0.07)	PD5	0 (0)	0.02 (0)
E	1.8 (0.26)	1.31 (0.25)	.	.	.

Statistical comparisons were made only between groups in the same row (e.g., OE4 for 21 and under versus 21 and over). Comparisons were not made between different levels (e.g., OE4 versus OE3). DTBF: Daily tooth brushing frequency, TBD: Tooth brushing duration, OCD: Obsessive-compulsive disorder, OCI-R: Obsessive-Compulsive Inventory-Revised, M1/M2/M3/M4: Miller gingival recession, OE: Occlusal enamel, BE: Buccal enamel, C: Cervical, PE: Palatinal enamel, OD: Occlusal dentine, BD: Buccal dentine, PD: Palatinal dentine, E: Extracted

admitted to the clinic. The main findings of our study were the absence of a strong expected relationship between OCI-R scores and tooth wear or gingival recession, but the presence of weak-to-moderate correlations between the ordering subscale and certain occlusal tooth wear parameters.

In our study, the OCI-R scale was used to assess obsessive-compulsive symptoms. This scale was preferred due to its strong psychometric properties and widespread use in both clinical and research settings.[20,21] In a validation study conducted in a clinical sample, Abramovitch and Deacon reported that the OCI-R is an empirically validated tool that can be used in OCD research across various clinical and research contexts.[20] For the evaluation of tooth wear, the ETI was chosen because of its ease of application and ability to provide standardized measurements. In a prevalence study conducted by Bartlett and colleagues among young adults in Europe, they reported that the index was preferred for measuring the severity and distribution of tooth wear because it allowed ease of use in clinical practice and standardized recording.[22] For the classification of gingival recession, the Miller classification was used. This classification has been widely adopted in the literature because of its prognostic value in the clinical decision-making process and its guidance for treatment planning. In a systematic review, Chambrone and Avila-Ortiz[23] stated that the vast majority of clinical studies published to date have used the Miller classification, due to its prognostic value and broad acceptance in clinical application.

In our study, of the 143 participants from the general population, 27 (18.9%) scored ≥21 on the OCI-R cut-off and were considered to show OCD symptoms, while 116 (81.1%) scored below this threshold (Table 2). This distribution is consistent with findings reported in the literature regarding prevalence rates in general population and non-clinical samples Although age distribution was balanced, females brushed their teeth more frequently than males, and individuals under the age of 35 brushed more frequently,

Table 4. Correlation between OCI-R subgroups and tooth wear scores

	OE0	OE1	OE2	OE3	OE4	OD0	OD1	OD2	OD3	OD4
OCI-R	.	-0.042	-0.079	0.154	0.028	-0.099	0.052	0.094	0.004	.
Washing	.	-0.042	-0.006	0.114	0.014	-0.026	-0.048	0.068	0.081	.
Checking	.	0.063	-0.148	0.113	0.084	-0.036	-0.057	0.085	0.027	.
Ordering	.	-.169*	-0.043	.255**	-0.069	-.254**	.202*	.188*	-0.009	.
Obsessing	.	-0.007	-0.084	0.091	0.121	-0.038	-0.01	0.104	-0.027	.
	BE0	**BE1**	**BE2**	**BE3**	**BE4**	**BD0**	**BD1**	**BD2**	**BD3**	**BD4**
OCI-R	.	0.027	0.114	-0.093	-0.027	0.021	0.055	0.072	0.046	0.131
Washing	.	0.003	0.113	-0.124	-0.035	0.011	0.039	0.035	0.071	.
Checking	.	0.095	0.009	-0.054	-0.031	0.116	0.032	0.024	0.156	.
Ordering	.	-0.03	0.16	-0.161	-0.022	0.005	0.056	0.046	0.115	.
Obsessing	.	0.061	0.067	-0.08	-0.113	0.084	0.04	0.002	0.112	.
	PE0	**PE1**	**PE2**	**PE3**	**PE4**	**PD0**	**PD1**	**PD2**	**PD3**	**PD4**
OCI-R	.	0.047	0.014	-0.094	-0.078	0.084	0.085	-0.029	-.169*	-0.121
Washing	.	0.027	0.039	-0.004	-0.109	0.069	0.023	-0.091	-0.135	.
Checking	.	0.052	0.009	-0.098	0.004	0.114	-0.081	-0.138	-0.061	.
Ordering	.	0.063	0.025	-.189*	-0.098	0.079	-0.083	-.234**	-0.129	.
Obsessing	.	0.061	0.005	-0.078	-0.067	0.095	-0.002	-.174*	-0.102	.
	C0	**C1**	**C2**	**C3**						
OCI-R	0.093	-0.126	0.069	-0.063						
Washing	0.052	-0.077	0.062	-0.007						
Checking	.190*	-0.161	-0.036	-0.107						
Ordering	-0.001	-0.079	0.137	-0.055						
Obsessing	.184*	-0.149	-0.014	-0.114						

*The correlation is significant at the 0.01 level.
**The correlation is significant at the 0.05 level.
OCI-R: Obsessive-Compulsive Inventory-Revised, OE: Occlusal enamel, BE: Buccal enamel, C: Cervical, PE: Palatinal enamel, OD: Occlusal dentine, BD: Buccal dentine, PD: Palatinal dentine

consistent with previous studies.[24] These demographic differences indicate that oral health behaviors are influenced by gender and age factors (**Table 1, and 3**).

In our study, there was no difference in the amount of gingival recession between individuals with and without OCD symptoms. Conflicting results exist among similar studies in the literature. Moharrami et al.,[7] in a comparative study with 92 participants, reported no significant difference in gingival recession between individuals with OCD symptoms and the control group. In that study, despite higher brushing frequency and Lower Plaque Index in the OCD group, the amount of gingival recession was found to be similar. The Canadian Dental Hygienists Association reported that obsessive cleaning-oriented behaviors may lead to gingival recession, gingival irritation, and tooth sensitivity.[25] Philip et al.,[26] in a case series study on the dental manifestations of OCD, reported that enamel injuries, gingival changes, and tooth wear were the most common dental findings. It is known that gingival recession in OCD patients depends not only on brushing frequency but also on factors such as brushing technique, type of toothbrush used, and the amount of force applied. In conclusion, the findings suggest that increased brushing frequency in OCD patients does not necessarily lead to gingival recession, and that when proper technique is used, it may even have a protective effect. Based on these findings, our first hypothesis-that there is no difference in the amount of gingival recession between individuals with and without OCD symptoms-was accepted.

To the best of our knowledge, no study has directly examined the relationship between OCD and tooth wear. In a recent study with 240 participants, Özyurt et al.[27] reported that OCD was significantly higher in the bruxism group compared to the control group, and that the frequency of bruxism was increased in the OCD group. Bruxism is known to be one of the causes of tooth wear, and it has been reported that 93% of wear in occlusal contact areas is attributed to bruxism.[28] These findings suggest that there may be a relationship between OCD symptoms and bruxism. However, in our study, no significant correlation was found between the total OCI-R score and tooth wear parameters (**Table 4**). On the other hand, weak-to-moderate positive correlations were identified between the ordering subscale and OM3, OD1, and OD2 (**Table 4**). This finding suggests that individuals may be in constant search of achieving a perfectly correct occlusion. Those with ordering obsessions may repeatedly engage in tightening and relaxing their jaw muscles to ensure proper tooth closure, which may lead to occlusal surface wear.[29] In a study conducted by Piccoli et al.[28] on patients with mental disorders, a direct correlation between psychiatric disorders and tooth wear was reported, and chronic exposure to neuroleptic drugs was found to induce bruxism phenomena. These findings support the association identified in our study between the ordering subscale and occlusal wear. The fact that the washing subscale showed the highest scores, and that individuals with OCI-R symptoms exhibited higher daily tooth brushing frequency, is consistent with the findings of Moharrami et al.[7] (**Table 2**). In

that study, OCD patients were reported to have significantly higher brushing frequency and lower caries experience compared to the control group.

In our study, the finding that buccal wear scores, except for BM2, were generally higher in the healthy group was unexpected. This may suggest that excessive brushing behavior in individuals with OCD symptoms could have a protective effect on buccal surfaces. In a study conducted by Martinovic et al.[4] among biomedical students, it was shown that obsessive-compulsive personality disorder traits may positively influence oral health behaviors through characteristics such as perfectionism and attention to detail. This finding may explain the higher brushing frequency observed in our study. Based on the findings obtained, our second hypothesis-that there is no difference in tooth wear scores between individuals with and without OCD symptoms-was partially accepted.

Limitations

There are various limitations to our study. Its cross-sectional design makes it impossible to establish causal linkages. Longitudinal investigations are required to assess causality, given the findings only suggest concurrent relationships. The very small sample size is another drawback, which could result in lower statistical power, especially in subgroup analysis. In addition, none of the participants had a formal diagnosis of OCD, meaning that they were not experiencing the disorder at a clinical level. While an OCI-R score above 21 indicates the presence of marked obsessive-compulsive symptoms, this may still represent a milder level compared to clinically diagnosed OCD. Therefore, future studies that directly compare clinically diagnosed OCD patients with healthy controls are needed to better clarify the long-term effects of obsessive behaviors on oral health.

CONCLUSION

As a result, although our study did not identify a strong relationship between OCD symptoms and tooth wear, the association between the ordering subscale and occlusal wear is noteworthy. The higher tooth brushing frequency observed in OCD patients indicates that their oral health behaviors differ from those of healthy individuals. These findings emphasize the importance of a multidisciplinary approach and highlight the necessity for dentists to consider patients' mental health status when planning treatment. Monitoring occlusal wear in patients with OCD symptoms is recommended. It is important for dentists to recognize excessive brushing behaviors in OCD patients and provide appropriate oral hygiene education. The use of soft toothbrushes and instruction on proper brushing techniques in these patients may help prevent potential damage.

ETHICAL DECLARATIONS

Ethics Committee Approval

The study was carried out with the approval of the İnönü University Clinical Researches Ethics Committee (Date: 24.06.2025 Decision No: 2025/7774).

Informed Consent

All patients signed and free and informed consent form.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financialsupport.

Author Contributions

All of the authors declare that they have all participated inthe design, execution, and analysis of the paper, and that theyhave approved the final version

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Comparison of the effects of different surface treatment methods on the bonding strength of CAD/CAM blocks to repair composites

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ABSTRACT

Aims: The aim of our study is to evaluate the effects of surface treatments performed prior to composite resin repair on the shear bond strength of one ceramic CAD/CAM material (IPS e.max) and two different CAD/CAM materials with resin additions (Lava Ultimate and Vita Enamic) and to investigate the contribution of milling roughening to other surface treatments.

Methods: In our study, a total of 189 samples with a thickness of 2 mm were prepared, with 63 samples from each of the IPS e.max, Lava Ultimate, and Vita Enamic blocks. The test materials were divided into nine subgroups based on surface treatment techniques (phosphoric acid, HF acid, sandblasting, Cojet, milling + phosphoric acid, milling + HF acid control, milling + sandblasting, milling + Cojet, and control). After the thermal cycling process was applied, silane + bond + composite resin was applied to all sample surfaces. Subsequently, the samples were subjected to a shear bond strength test. Fracture types were evaluated using a stereomicroscope and SEM. Data were analyzed using the Mann-Whitney U, Kruskal-Wallis H, and post-hoc tests.

Results: It was found that the differences between all materials in terms of bonding strength were statistically significant (Vita Enamic > Lava Ultimate > IPS e.max) ($p<0.05$). The bond strength of the control group was found to be statistically significantly lower than that of the HF acid surface treatment (HF acid > Cojet > Sandblasting > Phosphoric acid > Control) ($p<0.05$). The highest number of adhesive fractures was observed in the IPS e.max material after all surface treatments, while the highest number of mixed fractures was detected in the Lava Ultimate and Vita Enamic materials. Although milling increased bond strength, it was not statistically significant ($p>0.05$).

Conclusion: Surface treatments applied prior to the repair of ceramic materials with composite resin have increased the bonding strength.

Keywords: CAD/CAM ceramics, composite resin, surface roughening, bonding strength, repair

INTRODUCTION

One of the most preferred materials in indirect restoration in dentistry is dental ceramics. These materials, which can mimic the translucency and color depth of natural teeth, are highly resistant to wear and biocompatible.[1,2] Compared to other materials, they cause less plaque accumulation. Their thermal expansion coefficients are similar to those of dental tissues, and they are corrosion-resistant. Due to the strong intermolecular bonds in their structure, they are resistant to chemical substances. Dental ceramics are primarily composed of feldspar, kaolin, and quartz.[3] Feldspar (70-80%) provides transparency to the material, while kaolin (3-5%) provides opacity. Quartz (10-30%) increases dimensional stability and durability.[4]

Dental ceramics are classified according to their general structure as glass-matrix ceramics, polycrystalline ceramics, and resin-matrix ceramics.[5,6] Based on their crystal structures, they are categorized as aluminum oxide, magnesium aluminum oxide, zirconium oxide, leucite, lithium disilicate, lithium phosphate mica, and fluorapatite. Based on their manufacturing techniques, they are grouped into systems that are shaped by heat and pressure, castable, slip-cast, or prepared using CAD/CAM technology.[4]

In CAD/CAM systems, the three-dimensional design of the restoration is created in a computer environment after taking optical measurements with an intraoral scanner.[7] Thus, there is no need for traditional measurement procedures and temporary crown treatment, and the risk of cross-infection is eliminated.[8] Thanks to this system, which uses special blocks made from different materials, restoration production is completed in a single session without the need for laboratory procedures.[9] Commonly preferred materials include feldspathic ceramics, glass ceramics reinforced with

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lithium disilicate or leucite, oxide ceramics, glass ceramics reinforced with lithium silicate and zirconia particles, resin matrix ceramics, composites, polymers, and certain metals.[10]

The main structure of feldspathic ceramic blocks, which can mimic the natural tooth color due to their high glass content, is composed of silica and feldspar particles (30%).[11,12] Prior to cementation, these materials undergo a roughening process using hydrofluoric (HF) acid.[13] Glass ceramics reinforced with lithium disilicate (70%)[14] are used only as substructure materials because they strengthen the substructure of ceramic restorations and reduce light transmission. Ceramics reinforced with leucite (17-25%) undergo greater shrinkage compared to feldspathic ceramics. Since they exhibit aesthetics and wear similar to natural teeth, they are preferred in metal-free inlay/onlay and crown restorations.[15]

In glass-infiltrated oxide ceramics, which have superior physical and mechanical properties, glass is infiltrated into the spaces between alumina or zirconia crystals in an attempt to eliminate the porous structure. The absence of glass in the composition of polycrystalline ceramics has increased their fracture resistance.[16] Both glass-infiltrated and polycrystalline ceramics undergo a silica coating (tribochemical blasting) process on their inner surfaces using a Cojet device.[17] Resin matrix ceramics, on the other hand, are produced to combine the positive properties of ceramics (75%) and composite resins. The voids between the sintered matrix structures of these materials are filled with polymer. This procedure reduces the risk of cracking commonly encountered in ceramic materials.[18] Since resin matrix ceramics are polymerized at high temperatures during production, they do not require any firing or glazing after the carving process. They are commonly preferred for inlay/onlay, full crown, and laminate veneer restorations in patients with bruxism.[19]

For clinical applications, it is generally recommended to use CAD/CAM blocks (IPS e.max, Lava Ultimate, Vita Enamic, Cerec Blocks, VitaMark II, etc.) that offer the advantages of both ceramic and composite resin.[20,21] IPS e.max blocks, reinforced with lithium disilicate crystals (40%), have a semi-crystalline glass-ceramic structure.[22,23] Lava Ultimate blocks, composed of a resin and nano-ceramic mixture, contain nano-ceramic particles (80%) embedded in the resin matrix.[24] Vita Enamic hybrid ceramic blocks contain feldspar (86%) and polymer (14%).[23]

The primary causes of failure in CAD/CAM-produced posterior restorations include improper tooth treatment, parafunctional habits, trauma, loss of adhesive bonding, internal stresses generated during production, and localized fractures caused by porosity within the material.[25,26] Such situations require the restoration to be completely replaced or repaired. Replacing the restoration causes trauma to the tooth surface, time loss, and additional costs. Repairing the restoration allows it to regain function and aesthetics in a short time and at low cost.[25,27]

Removing the restoration for repair outside the mouth increases the risk of fracture in the tooth.[27] This is why intraoral repair procedures have gained prominence. In intraoral repair of restorations, the use of composite resins capable of bonding to ceramic materials or the bonding of broken ceramic pieces using resin cement is considered.[28] The type, composition, and particle size of the composite resin to be used are the most important factors affecting bonding strength and the success of the repair process.[29,30]

To increase the bonding strength of the restoration materials to be used, it is recommended that the exposed fracture surfaces be subjected to certain mechanical or chemical processes (milling, acid or laser etching, sandblasting with aluminum oxide/silica-modified aluminum oxide particles).[31-33] Milling roughening removes the unsupported ceramic structure and smear layer, creating an area conducive to bonding. However, the use of a burr can cause cracks to form throughout the ceramic.[34] Acid etching (HF acid, phosphoric acid, or APF gel) is preferred, especially on glass ceramic surfaces.[35,36] HF acid is recommended for surface treatment of ceramics containing more than 15% silica oxide.[37,38]

On oxide ceramic or metal surfaces, the air abrasion/blasting method (spraying Al_2O_3 particles at a pressure of 2-2.5 bar, from a distance of 10 mm, for 10-15 seconds at a right angle to the ceramic surface) is used to ensure micromechanical retention.[39] The most significant disadvantage of this application is that it may cause surface damage during restoration and predispose to fractures in the long term.[40] In acid-resistant ceramics with high crystal content (aluminum or zirconium), the ceramic surface is more often roughened with silica-modified aluminum oxide particles.[41] This method increases the silica content of the ceramic, enabling it to react better with the bonding silane agent.[42]

The aim of our study is to determine the effect of different surface treatments on the bond strength of composite resin in fractures that may occur in two different CAD/CAM materials with resin addition (Lava Ultimate, Vita Enamic) and one ceramic CAD/CAM material (IPS e.max).

METHODS

This study did not require ethical approval as it did not involve any human subjects or animal experiments. All procedures were carried out in accordance with the ethical rules and the principles.

The materials used in the study are shown in **Table 1**.

The IPS e.max lithium disilicate glass ceramic test specimens used in the study were produced from CAD LT A2 C14-coded CAD/CAM blocks (12x14x18 mm). Lava Ultimate resin hybrid nano-ceramic test specimens were produced from A2 LT 14L-coded CAD/CAM blocks (12x14x18 mm). The Vita Enamic hybrid ceramic test samples were produced from CAD/CAM blocks (12x14x18 mm) coded 2M2-T EM-14. Using a minitom precision cutting device (at a speed of 200 rpm), 63 samples measuring 12x14 mm and 2 mm thick were prepared from the surface of all blocks. After the burrs on the edges of the samples were smoothed with a ceramic finishing bur, they were cleaned with distilled water. IPS e.max samples were crystallized in a porcelain furnace according to the manufacturer's recommendations.

All material samples were embedded in 3x3x2 cm autopolymerizing acrylic resin molds with the surfaces to be treated exposed. Prior to surface treatment, the samples were leveled with 600, 800, and 1200 grit silicon carbide abrasives. The samples were soaked in distilled water for 10 minutes and dried with an air spray. A total of 63 acrylic blocks per material were divided into nine subgroups of seven each for different surface treatments (**Figure 1**).

Table 1. Materials used in the study

Materials	Content of the materials	Lot number	Manufacturer
IPS e.max	Lithium disilicate glass ceramic (SiO2 57-80%, Li2O 11-19%, K2O 0-13%, P2O5 0-11%, ZrO2 0-8%, ZnO 0-8%, others and coloring oxides 0-12%)	V33396	Ivoclar Vivadent, Schann, Liechtenstein
Lava Ultimate	Resin nano-ceramic (BisGMA/TEGDMA, By weight 80% nano-ceramic)	N652686	3M, St. Paul, USA VITA, Zahnfabrik, Bad Sackingen, Germany
Vita Enamic	Hybrid Ceramics (UDMA, By weight 86% feldspar ceramics, 14% polymer, 58-63% SiO2, 20-23% Al2O3, 9-11% Na2O, 4-6% K2O, 0.5-2% B2O3, <1% Zr2O and CaO)	54210	VITA, Zahnfabrik, Bad Sackingen, Germany
Filtek Z250	BIS-GMA, UDMA, BIS- EMA, zirconia/silica fillers	N879677	3M ESPE, Seefeld, Germany
Ultradent Porcelain Etch	9% hydrofluoric acid	BDMZW	Ultradent Products Inc, USA
Panora 200 Etch	37% phosphoric acid	18025	Imicryl
Cojet	30 µm Al2O3	644521	3M ESPE
Clearfil Ceramic Primer Plus	3-Methacryloxypropyl-trimethoxysilane 10-MDP, Ethanol	6K0027	Kuraray Noritake Dental Inc, Sakazu, Kurashiki, Okayama, Japan
Clearfil S^3 Bond	10-Methacryloyloxydodecyl dihydrogen phosphate (MDP) Bisphenol A diglycidyl methacrylate (Bis-GMA) 2-hydroxyethyl methacrylate (HEMA) Hydrophobic dimethacrylate dl-camphorquinone Ethyl alcohol, Water, Silanized colloidal silica	230015	Kuraray Noritake Dental Inc, Sakazu, Kurashiki, Okayama, Japan
Korox	50 µm	14171620912	Bego, Bremen, Germany

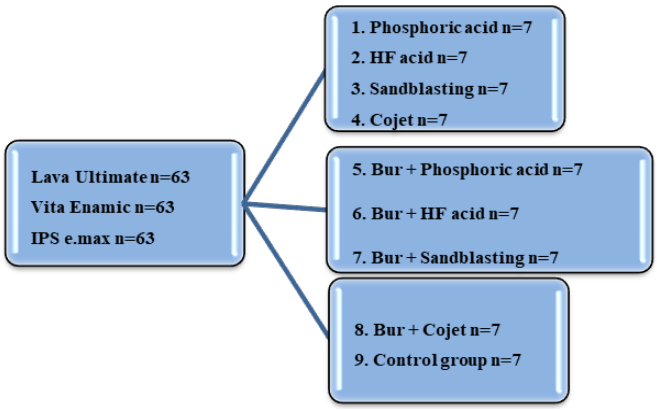


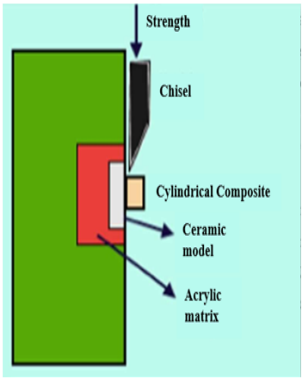
Figure 1. Distribution of test models according to groups

For each material, a 37% phosphoric acid gel was applied to the surface of the samples in the first group for 20 seconds, then washed with an air-water spray for 10 seconds and dried. For the second group of samples, a 9% HF acid gel was applied to the surface for 90 seconds, then washed with an air-water spray for 20 seconds and dried. The surface of the samples in the third group was treated with 50 µm Al_2O_3 sand at a pressure of 2.8 bar, from a distance of 10 mm, at an angle of 90°, for 10 seconds, using a sandblasting device. The sandblasted samples were cleaned in distilled water for 5 minutes. The surfaces of the samples in the fourth group were coated with silica using a Cojet system (at a pressure of 2.3 bar, from a distance of 10 mm, at an angle of 90°, for 15 seconds, with Si_2O sand particles of 30 µm in size) and cleaned with distilled water.

The surfaces of the samples in the fifth group were roughened using a green belt flame shape bur (150 µm) and 37% phosphoric acid gel. The surfaces of the samples in the sixth group were treated with green belt flame shape bur + 9% HF acid. The surfaces of the samples in the seventh group were roughened using a green belt flame shape bur + Al_2O_3 sandblasting process. The surfaces of the samples in the eighth group were treated with a green belt flame shape bur + Cojet process. The samples in the ninth group, which were not subjected to surface treatment, were separated as a control group and cleaned with distilled water.

Clearfil Ceramic Primer Plus was applied to the surface of all prepared samples and allowed to evaporate for 60 seconds. Clearfil S3 bond was applied using an application brush for 20 seconds and polymerized for 10 seconds using an LED light device with a light intensity of 800-1000 mW/cm^2, in accordance with the manufacturer's recommendations. After completing the surface treatments, composite resin material (Filtek Z250) was applied to the surface of all samples using plastic tubes with a diameter and height of 5 mm, using a layering technique, and polymerized with an LED light device. After removing the plastic tubes, light was applied for 60 seconds from four different angles. After the samples were kept in an oven for 24 hours (in distilled water at 37°C), they were subjected to 1000 thermal cycles at 5-55°C (with a soak time of 40 seconds and a transfer time of 6 seconds). They were then kept in the oven again for 24 hours.

The shear bond strength measurements of the samples were performed at the Research Laboratory of the Faculty of Dentistry, Erciyes University. During the measurement, the operator placed the metal tip of the universal testing machine (Instron), which ended in a knife edge, parallel to the composite-ceramic interface (**Figure 2**). Force was applied at a rate of 0.5 mm per minute. After obtaining the force value at the moment the composite sample separated from the ceramic surface, the shear bond strength was calculated using the following formula (in MPa) by dividing the force value by the surface area of the fracture zone (19.625 mm^2).



$$S = \frac{F}{A}$$

S= Shear bond strength (MPa)
F= Force at breaking point (N)
A= Area at the attachment point (mm2)

Figure 2. Shear test procedure

All samples were examined under a stereomicroscope (at 10x magnification) to determine the type of fracture. Fractures occurring at the composite/ceramic interface were classified as adhesive fractures, those occurring within the composite layer or ceramic were classified as cohesive fractures, and those involving both adhesive and cohesive fractures were classified as mixed fractures. Samples that fractured without being subjected to testing were classified as premature fractures. All samples were coated with approximately 45 Angstroms of Au/Pd (80% Au, 20% Pd) for 15 seconds and imaged and photographed under SEM at magnifications of x200, x500, x1000, and x2000. The obtained data were analyzed using IBM SPSS Statistics Version 22 software and statistically evaluated using the Shapiro-Wilk test. The Mann-Whitney U and Kruskal-Wallis H tests were used to examine the differences between the groups. If the differences were found to be significant, a post-hoc multiple comparison test was used.

RESULTS

In groups where milling was not applied, In IPS e.max material, the bond strength of the sandblasting surface treatment was found to be statistically significantly lower than that of the HF acid and phosphoric acid groups, and the bond strength of the Cojet and control groups was also found to be statistically significantly lower than that of the phosphoric acid group ($p<0.05$). In Lava Ultimate material, the bond strength of the control group was found to be statistically significantly lower than that of the Cojet and HF acid surface treatments ($p<0.05$). In Vita Enamic material, the bond strength of the phosphoric acid group was found to be statistically significantly lower than that of the HF acid and sandblasting surface treatments ($p<0.05$) (**Table 2**).

In the Cojet, HF acid, and sandblasting surface treatment groups, the bonding strength of IPS e.max material was found to be statistically significantly lower than that of Vita Enamic material ($p<0.05$). In the phosphoric acid treatment group, no statistically significant differences were observed between the bond strengths of the materials ($p>0.05$). In the control surface treatment group, the bond strengths of IPS e.max and Lava Ultimate materials were found to be statistically significantly lower than that of Vita Enamic material ($p<0.05$) (**Table 3**).

In the groups treated with milling, in IPS e.max material, the bonding strength of Cojet and sandblasting surface treatments was found to be statistically significantly lower than that of HF acid surface treatments ($p<0.05$). In Lava Ultimate material, the bond strength of the phosphoric acid group was found to be statistically significantly lower than that of Cojet and HF acid surface treatments ($p<0.05$). In Vita Enamic material, the bond strength of the HF acid group was found to be statistically significantly lower than that of the Cojet surface treatment ($p<0.05$) (**Table 4**).

In the Cojet and Sandblasting surface treatment groups, the bonding strength of IPS e.max material was found to be statistically significantly lower than that of Lava Ultimate and Vita Enamic materials ($p<0.05$). In the HF acid surface treatment group, the bond strength of IPS e.max material was found to be statistically significantly lower than that of Lava Ultimate material ($p<0.05$). In the phosphoric acid surface treatment group, the bond strengths of IPS e.max and Lava Ultimate materials were found to be statistically significantly lower than that of Vita Enamic material ($p<0.5$) (**Table 5**).

The effect of milling on bonding strength for surface treatments was not found to be statistically significant ($p>0.05$) (**Table 6**).

It was found that the differences between all materials in terms of bonding strength were statistically significant (Vita Enamic > Lava Ultimate > IPS e.max) ($p<0.05$) (**Figure 3**).

Table 2. Bond strength of materials in the non-bur group according to different surface treatments

		Bond strength (Mpa)						Kruskal-Wallis H Test	
The group without bur application		**n**	**Mean**	**Median**	**Min**	**Max**	**SD**	**Rank Avg.**	**H**	**p**
IPS e.max	Cojet	7	5.39	5.22	3.81	7.78	1.37	13.71	26.033	0.001
	HF acid	7	9.21	8.89	7.63	12.73	1.71	25		
	Phosphoric acid	7	12.85	13.78	9.42	14.64	2	31.43		
	Sandblasting	7	3.44	2.49	1.36	6.75	2.1	7.43		
	Control	7	5.1	4.91	2.47	8.46	1.9	12.43		
	Total	35	7.2	6.23	1.36	14.64	3.85		4-2 4-3 5-3 1-3	
Lava Ultimate	Cojet	7	10.21	11.55	3.56	17.82	5.79	22	14.915	0.005
	HF acid	6*	12.87	12.71	9.68	17.09	2.38	24.83		
	Phosphoric acid	7	7.08	3.93	2.2	13.65	4.94	14		
	Sandblasting	7	8.75	6.01	4.09	15.96	5.06	21.14		
	Control	7	3.41	3.5	2.54	3.87	0.44	6.57		
	Total	34	8.33	5.51	2.2	17.82	5.11		5-1 5-2	
Vita Enamic	Cojet	7	12.94	12.87	9.36	18.27	3.01	11.57	17.012	0.002
	HF acid	7	16.47	15.72	13.01	18.84	2.28	24.71		
	Phosphoric acid	7	11.99	11.63	10.39	15.05	1.86	8		
	Sandblasting	7	17	17.31	13.29	19.95	2.11	26.14		
	Control	7	15.41	15.1	14.57	16.83	0.96	19.57		
	Total	35	14.76	15.02	9.36	19.95	2.84		3-2 3-4	

*Groups with premature fractures, Min: Minimum, Max: Maximum, SD: Standard deviation

Table 3. Bond strength of different surface treatments according to materials in the non-bur group

The group without bur application		Bond strength (Mpa)						Kruskal-Wallis H test	
		n	Mean	Median	Min	Max	SD	Rank Avg.	H	p
Cojet	IPS e.max	7	5.39	5.22	3.81	7.78	1.37	6.14		
	Lava Ultimate	7	10.21	11.55	3.56	17.82	5.79	11.57	7.688	0.021
	Vita Enamic	7	12.94	12.87	9.36	18.27	3.01	15.29		
	Total	21	9.51	9.36	3.56	18.27	4.85		1-3	
HF acid	IPS e.max	7	9.21	8.89	7.63	12.73	1.71	4.57		
	Lava Ultimate	6*	12.87	12.71	9.68	17.09	2.38	10.5	14.059	0.001
	Vita Enamic	7	16.47	15.72	13.01	18.84	2.28	16.43		
	Total	20	12.85	12.72	7.63	18.84	3.71		1-3	
Phosphoric acid	IPS e.max	7	12.85	13.78	9.42	14.64	2	14.43		
	Lava Ultimate	7	7.08	3.93	2.2	13.65	4.94	6.86	5.351	0.069
	Vita Enamic	7	11.99	11.63	10.39	15.05	1.86	11.71		
	Total	21	10.64	11.63	2.2	15.05	4.04			
Sandblasting	IPS e.max	7	3.44	2.49	1.36	6.75	2.1	5.14		
	Lava Ultimate	7	8.75	6.01	4.09	15.96	5.06	10.21	14.382	0.001
	Vita Enamic	7	17	17.31	13.29	19.95	2.11	17.64		
	Total	21	9.73	6.75	1.36	19.95	6.56		1-3	
Control	IPS e.max	7	5.1	4.91	2.47	8.46	1.9	10		
	Lava Ultimate	7	3.41	3.5	2.54	3.87	0.44	5	15.636	0.001
	Vita Enamic	7	15.41	15.1	14.57	16.83	0.96	18		
	Total	21	7.98	4.91	2.47	16.83	5.56		2-3 1-3	

*Groups with premature fractures, Min: Minimum, Max: Maximum, SD: Standard deviation

Table 4. Bond strength of materials in the bur applied group according to different surface treatments

Bur applied group		Bond strength (Mpa)						Kruskal-Wallis H test	
		n	Mean	Median	Min	Max	SD	Rank Avg.	H	p
IPS e.max	Cojet	7	2.42	1.94	1.09	3.96	1.2	8.43		
	HF acid	7	10.95	10.54	8.4	16.25	2.6	23	16.797	0.001
	Phosphoric acid	6*	3.77	3.28	3.11	5.18	0.87	13.67		
	Sandblasting	6*	2.44	1.81	1.08	5.16	1.56	8.17		
	Total	26	5.03	3.38	1.08	16.25	4.04		4-2 1-2	
Lava Ultimate	Cojet	7	13.89	14.67	9.41	16.37	2.4	17.29		
	HF acid	7	15.52	15.93	10.39	21.99	4.25	19.29	14.968	0.002
	Phosphoric acid	7	5.74	5.75	4.41	7.54	1.19	4.29		
	Sandblasting	6*	12.99	12.18	6.44	20.53	4.61	15.33		
	Total	27	12	11.89	4.41	21.99	5		3-1 3-2	
Vita Enamic	Cojet	6*	18.26	18.1	14.48	21.27	2.26	22.17		
	HF acid	7	13.87	13.91	12.17	15.91	1.44	8.29	10.076	0.018
	Phosphoric acid	7	15	15.61	11.84	16.95	1.86	13.29		
	Sandblasting	7	15.27	14.62	13.83	18.15	1.75	13.43		
	Total	27	15.5	14.74	11.84	21.27	2.35		2-1	

*Groups with premature fractures, Min: Minimum, Max: Maximum, SD: Standard deviation

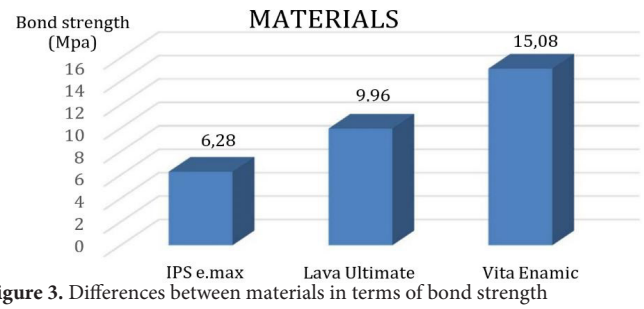


Figure 3. Differences between materials in terms of bond strength

The bond strength of the control group was found to be statistically significantly lower than that of the HF acid surface treatment (HF acid > Cojet > Sandblasting > Phosphoric acid > Control) ($p<0.05$) (**Figure 4**).

The types of fractures identified at 10x magnification under a stereomicroscope at the ceramic-composite interface are shown in **Table 7**. After all surface treatments, the highest number of adhesive fractures was observed in IPS e.max material, while the highest number of mixed fractures was

Table 5. Bonding strength of different surface treatments according to materials in the bur applied group

Bur applied group		Bond strength (Mpa)						Kruskal-Wallis H test	
		n	Mean	Median	Min	Max	SD	Rank Avg.	H	p
Cojet	IPS e.max	7	2.42	1.94	1.09	3.96	1.22	4		
	Lava Ultimate	7	13.89	14.67	9.41	16.37	2.4	11.71	15,287	0.001
	Vita Enamic	6*	18.26	18.1	14.48	21.27	2.26	16.67		
	Total	20	11.18	14.58	1.09	21.27	7.1		1-2 1-3	
HF acid	IPS e.max	7	10.95	10.54	8.4	16.25	2.6	6.29		
	Lava Ultimate	7	15.52	15.93	10.39	21.99	4.25	14.14	6,286	0.043
	Vita Enamic	7	13.87	13.91	12.17	15.91	1.44	12.57		
	Total	21	13.45	13.08	8.4	21.99	3.44		1-2	
Phosphoric acid	IPS e.max	6*	3.77	3.28	3.11	5.18	0.87	4.17		
	Lava Ultimate	7	5.74	5.75	4.41	7.54	1.1 9	9.43	15,567	0.001
	Vita Enamic	7	15	15.61	11.84	16.95	1.86	17		
	Total	20	8.39	5.75	3.11	16.95	5.21		1-3 2-3	
Sandblasting	IPS e.max	6*	2.44	1.81	1.08	5.16	1.56	3.5		
	Lava Ultimate	6*	12.99	12.18	6.44	20.53	4.61	11.5	12,492	0.002
	Vita Enamic	7	15.27	14.62	13.83	18.15	1.75	14.29		
	Total	19	10.5	12.59	1.08	20.53	6.34		1-2 1-3	

*Groups with premature fractures, Min: Minimum, Max: Maximum, SD: Standard deviation

Table 6. Effect of bur application on bond strength

	Bond strength (Mpa)						Kruskal-Wallis H test	
	n	Mean	Median	Min	Max	SD	Rank Avg.	z	p
No bur applied	104	10.12	10.72	1.36	19.95	5.22	89.25	-0.944	0.345
Bur applied	80	10.92	12.03	1.08	21.99	5.85	96.73		
Total	184	10.46	11.59	1.08	21.99	5.5			

Min: Minimum, Max: Maximum, SD: Standard deviation

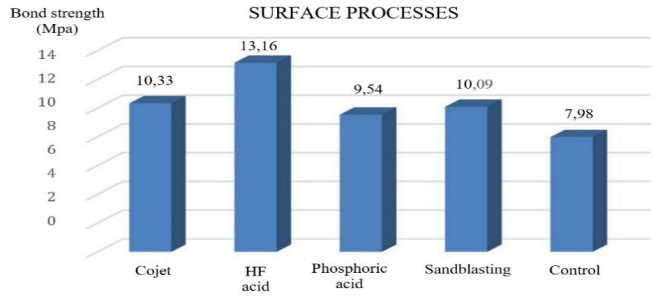


Figure 4. Differences between surface treatments in terms of bond strength

observed in Lava Ultimate material (except for milling + HF acid and milling + phosphoric acid). In the Vita Enamic material, mixed fractures were also the most common. In the control group, 100% adhesive fractures were observed in the IPS e.max and Lava Ultimate materials, while 71.4% cohesive fractures were observed in the Vita Enamic material (**Figure 5-9**).

SEM findings related to fracture types and materials observed at 2000x magnification using SEM are shown in **Figure 6-9**.

Table 7. Fracture types observed after shear bonding test

Surface procedure	Sandblasting	Bur+sandblasting	Cojet	Bur+Cojet	HF acid	Bur+HF acid	Phosphoric acid	Bur+phosphoric acid	Control
IPS e.max	85.7% Ad (6/7) 14.3% Kr (1/7)	100% Ad (6/6)*	85.7% Ad (6/7) 14.3% Kr (1/7)	85.7% Ad (6/7) 14.3% Kr (1/7)	71.4 %Ad (5/7) 28.6% Kr (2/7)	85.7% Ad (6/7) 14.3% Kr (1/7)	57.1% Ad (4/7) 42.9% Kr (3/7)	100% Ad (6/6)*	100% Ad (7/7)
Vita Enamic	85.7% Kr (6/7) %14.3Koh (1/7)	57.1% Kr (4/7) 42.9% Koh (3/7)	85.7% Kr (6/7) 14.3%Koh (1/7)	50% Kr (3/6)* 50% Koh (3/6)*	100% Kr (7/7)	57.1% Kr (4/7) 42.9% Ad (3/7)	100% Kr (7/7)	71.4% Kr (5/7) 28.6% Koh (2/7)	71.4% Koh (5/7) 28.6% Kr (2/7)
Lava Ultimate	85.7% Kr (6/7) 14.3% Ad (1/7)	83.8% Kr (5/6)* 16.2% Ad (1/6)*	57.1% Kr (4/7) 42.9% Ad (3/7)	100% Kr (7/7)	66.6% Kr (4/6)* 33.4% Ad (2/6)*	100% Koh (7/7)	71.4% Kr (5/7) 28.6% Ad (2/7)	57.1% Ad (4/7) 42.9% Kr (3/7)	100% Ad (7/7)

*Premature fracture seen during thermal cycling, Ad: Adhesive fracture, Kr: Mixed type fracture, Koh: Cohesive fracture

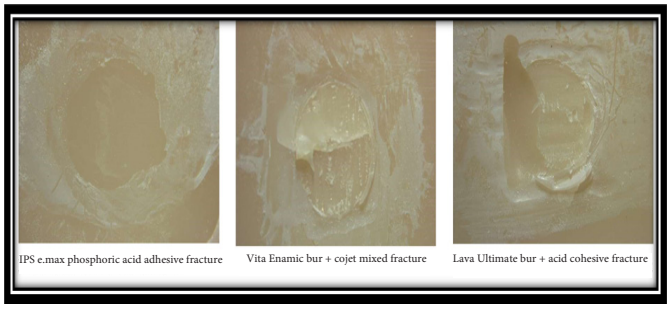


Figure 5. Fracture types

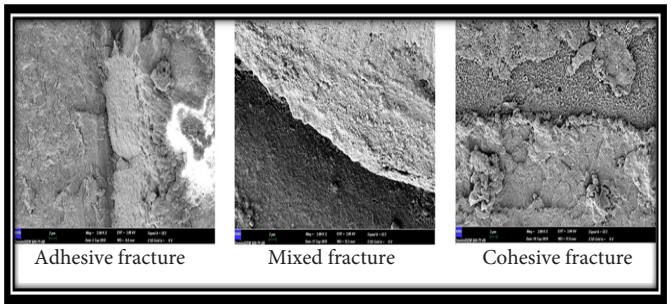


Figure 6. SEM (x2000) images of fracture types

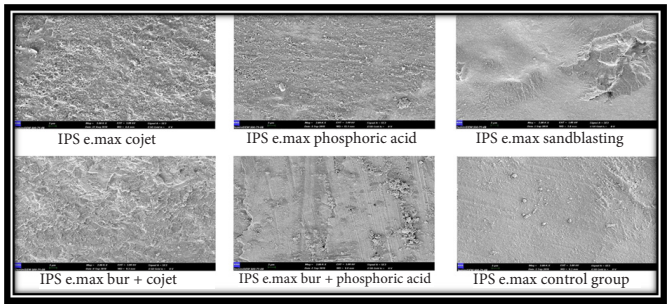


Figure 7. SEM (x2000) images of IPS e.max materials

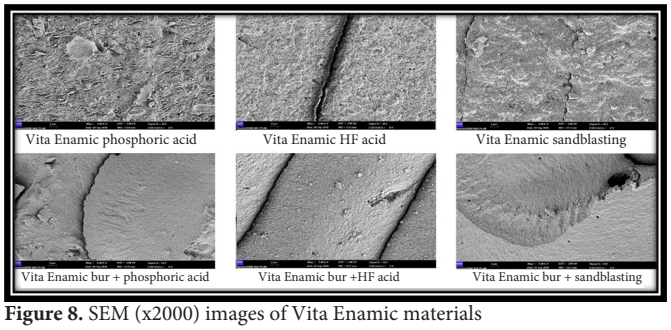


Figure 8. SEM (x2000) images of Vita Enamic materials

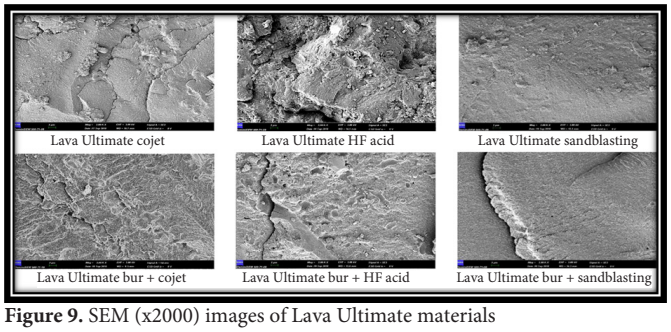


Figure 9. SEM (x2000) images of Lava Ultimate materials

DISCUSSION

The clinical lifespan of indirect restorations produced with CAD/CAM systems varies between 5 and 10 years on average.[43] The most important reason for their short lifespan is their low fracture resistance.[44] Since it is not possible to add intraoral porcelain to ceramic restorations, repairing localized fractures with composite resins has become a viable option.[24,45] The success of the composite resin repair procedure depends on the type of repair material and the bond strength between the ceramic and resin materials.[46] Hybrid composite resins exhibit higher bond strength than microfilled composites,[34,39] so microhybrid-based composite resin was used in our study.

Different test methods are used to calculate bond strength. Although these tests may not fully reflect clinical performance, they are useful in deciding which adhesive system to use in practice. Laboratory tests enable the mechanical testing of bonding surfaces and the determination of variables.[39] In the in vitro evaluation of bond strength, different test methods such as tensile, microtensile, shear, and microshear are utilized. The most significant disadvantage of the tensile test method is the formation of heterogeneous stresses that can cause cohesive fractures at the bonding interface.[47]

In the shear test method, a force is applied parallel to the bonding surface at a speed of 0.75±0.3 mm/min until the bond between the two materials bonded with the adhesive agent breaks. A loading speed higher than 1 mm/min may cause incorrect results.[48] The shear bond strength is calculated by dividing the maximum force applied by the surface area of the bonded surface.[49] Kalra et al.[50] reported that the bond strength must be at least 8-9 MPa for successful intraoral material repair. In our study using the shear bond strength test, the force was applied at a loading rate of 0.5 mm/min. To ensure that the obtained data could be compared accurately, the sample surfaces were standardized using 600, 800, and 1200 grit sandpaper, respectively.

For the bonding success of composite resin, mechanical methods such as roughening the fracture surfaces with a diamond bur or acid, sandblasting, or silica coating are recommended.[27] Wiegand et al.[51] reported that the highest bonding strength in terms of mechanical retention can be achieved by roughening with a burr (25-125-micron green band diamond burr). Jain et al.,[30] on the other hand, claimed that roughening with a burr causes microcracks on the ceramic surface.

HF acid, which is used to roughen silicate-containing ceramic surfaces, creates numerous pores in the matrix and crystal structure of the ceramic.[34] It has been stated that the concentration of HF acid and the roughening time should vary depending on the type of ceramic.[52] Vidotti et al.[53] emphasized that 10% HF acid can dissolve the glass matrix of IPS e.max material. In this case, the crystal structure is exposed, and the increased surface area also increases the wettability of the ceramic.[54] Although extending the application time increases the bond strength,[55,56] when HF acid is applied for a long time (>160 s), the glass phase dissolves faster than the crystalline phase, weakening the ceramic structure and reducing the bond strength.[57,58] Mokhtarpour et al.[59] reported that increasing the HF acid concentration and extending the etching time leads to an increase in mixed and cohesive fractures.

In a study, it was stated that HF acid does not increase the bonding strength of Vita Enamic hybrid ceramic material, and this fact is attributed to the material's high leucite and zirconia content.[60] It has been reported that phosphoric acid, used for roughening ceramic surfaces, only enables the

cleaning of contaminated surfaces but does not cause changes at the microstructural level.[61]

Given that acid applications can have toxic effects on living tissue, it has been recommended that ceramic materials be roughened using a sandblasting method. The size of Al_2O_3 particles affects the adhesion of the repair material. Smaller particles are preferred in glass, hybrid, or nano-ceramics, while larger particles are used in rigid materials such as zirconium. It has been claimed that sandblasting results in a more irregular surface morphology compared to roughening with HF acid.[62] Studies examining the ceramic surface of IPS e.max material after application of HF acid and Al_2O_3 using SEM reported that a more regular surface change was obtained after HF acid treatment.[63,64] Elsaka[24] found the surface roughness of Vita Enamic and Lava Ultimate material samples treated with sandblasting and HF acid to be similar. Colares et al.[65] stated that the application of HF acid + silane is sufficient for the repair of IPS e.max lithium disilicate ceramic materials with composite resin and that sandblasting should be avoided.

In a study where sample surfaces were roughened using diamond milling and sandblasting methods, it was found that after milling, unidirectional indentations and protrusions formed, while after sandblasting, the indentations and protrusions were found to be in different directions and orientations.[66] Güngör et al.[67] reported that the highest surface roughness values were observed in the groups treated with milling, followed by sandblasting and acid application methods. In our study, we observed that the irregular areas detected on the surface of the samples after sandblasting prevented the ceramic surface from being completely wetted by the bonding agents and caused voids at the interface. This suggests that further roughening would not lead to higher bonding strength.

Chemical surface treatments used to increase bonding strength (silane coating agent and bond application) are at least as effective as mechanical methods.[24,68] Due to their structure (being dual-functional), silanes can bond with both organic and inorganic materials. This property helps to form a strong bond between silica-containing ceramics and composite resin.[69] The same bond cannot be achieved with materials that do not contain silica.[11] Elsaka,[12] who applied a silica coating to Vita Enamic material using a Cojet device, noted that the application of silane to the surface resulted in the formation of covalent bonds between alumina, silica particles, and adhesive cement. Nagai et al.[70] also stated that silane application increased bonding strength.

The silica layer formed after applying the Cojet process to the ceramic surface provides the necessary environment for the silane to become active. Thanks to the chemical bond formed by the silane between the ceramic surface and the resin,[27] the ceramic-resin bond remains stable even after prolonged immersion in water and thermal cycling.[39] The ceramic-composite resin bond is exposed to chewing stresses in the mouth and is affected by thermal and chemical factors. Temperature changes in the mouth create stress between materials with different thermal expansion coefficients.27 To simulate such effects in a laboratory setting, it is recommended to soak the samples in artificial saliva at different temperatures and for different durations,[41] use devices such as chewing simulators, or perform thermal cycling.[39] In our study, the samples were subjected to thermal cycling. In the samples subjected to milling, low bond strength values (<8-9 MPa) were measured in the Cojet, phosphoric acid, and sandblasting groups of the IPS e.max material, and in the sandblasting group of the IPS e.max material in the samples not subjected to milling. This result suggests that sandblasting and Cojet treatment are not sufficiently effective in samples containing glass ceramics.

In recent years, bonding systems containing MDP (10-methacryloxydiethyl hydrogen phosphate monomer) have gained prominence in the intraoral repair of ceramic materials.[30] It is claimed that treating the ceramic surface with MDP primer increases its bonding ability.[19,42] In light of this information, Clearfil Ceramic Primer Plus was used in our study due to its MDP content.

The effect of combining mechanical and chemical processes on bond strength is controversial.[20,71,72] Elsaka[12] reported that applying HF acid or sandblasting to Vita Enamic material in combination with a silane pretreatment was more effective than mechanical surface treatment alone, but no such difference was observed in Lava Ultimate material. Cekic-Nagas et al.,[19] in a study using Vita Enamic, Lava Ultimate, and GC Cerasmart materials, found that the Vita Enamic material surface was rougher and more irregular than the others and exhibited higher bond strength. In our study, no significant difference in shear bond strength was detected between the groups with and without milling. This phenomenon is thought to be due to the use of an MDP-containing silane agent (hydrophobic siloxane bond) in all groups. When compared to resin-based materials such as Vita Enamic, Lava Ultimate, and ceramic-based IPS e.max materials, resin-based materials exhibited higher bond strength. We believe this result is due to the material containing more silica and a higher filler content. The higher bond strength of resin-containing hybrid ceramics (Vita Enamic and Lava Ultimate) is attributed to the materials' ability to form both micromechanical and chemical bonds.

In order to examine changes occurring on the surface of the material at a small scale, stereomicroscopes and SEM devices are used. In our study, premature fractures[63] observed in some samples before undergoing fracture testing were found to be adhesive fractures upon stereomicroscopic examination. While adhesive fractures were generally observed in IPS e.max material samples, mixed cohesive and adhesive fractures were observed in Vita Enamic and Lava Ultimate blocks, respectively. Our results are consistent with the findings of Peumans et al.,[73] who observed adhesive failure in IPS e.max materials,[72] and Hu and colleagues, who reported cohesive fractures in Vita Enamic material samples treated with HF acid + silane.

CONCLUSION

Roughening processes applied to ceramic surfaces increase bond strength. The effect of milling on bond strength was not found to be statistically significant ($p>0.05$). The lowest bond strength was observed in the control groups where no surface treatment was applied, while the highest bond values were measured in the samples treated with HF acid. In IPS e.max samples with a high ceramic content, phosphoric acid and milling + HF acid application increased bonding strength. In Lava Ultimate samples made of resin-reinforced materials,

Cojet and HF acid application increased bonding, while in Vita Enamic samples, sandblasting and HF acid application increased bonding. SEM examination of the surfaces of materials treated with sandblasting and Cojet revealed microporosity on the surface.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study did not require ethical approval as it did not involve any human subjects or animal experiments.

Informed Consent

Because the study has no study with human and human participants, no written informed consent form was obtained.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

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Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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Clinical experiences of dental students and recent graduates in prosthodontic treatments: a cross-sectional study*

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ABSTRACT

Aims: The aim of our study is to determine the treatment, planning, and X-Ray evaluation skills of 4th and 5th year dental students at our university and newly graduated dentists from our faculty, as well as the procedures they find difficult in the clinical stages of fixed and removable prostheses.

Methods: A total of 140 dental students and dentists were included in the study, comprising 55 fourth-year students, 45 fifth-year students who had completed their prosthetic dentistry internships, and 40 recent graduates from our faculty. To evaluate the clinical internship experiences of the dentists, a 27-question survey form was created using Google Forms, and the survey link was shared with the participants. The survey included 5-point Likert-type questions and closed-ended questions. The data obtained were statistically analyzed using the Pearson Chi-square test and the Bonferroni-corrected Z test.

Results: Significant differences were found among groups in terms of single-tooth preparation time (p=0.001), the effect of patient anxiety (p=0.027), and the most challenging steps in complete and removable denture procedures (p=0.002 and p=0.027, respectively). Half of the graduates completed single-tooth preparation in 15 minutes, while most 4th- and 5th-year students required 15-30 minutes. Fifth-year students were most affected by patient anxiety. In complete denture treatments, occlusal adjustment was generally reported as the most difficult step, whereas try-in denture was the most challenging for 5th-year students. In removable partial denture planning, patient-specific design was the most difficult stage for all groups, though the specific areas of difficulty varied by experience level.

Conclusion: This study demonstrated that clinical experience shortens procedure times in prosthodontic treatments while enhancing empathy and patient management skills. Nevertheless, occlusal adjustment in complete dentures and treatment planning in removable partial dentures remain the most critical challenges, regardless of experience level. These findings suggest that emphasizing these steps in prosthodontic education may enhance clinical efficiency and contribute to improved patient satisfaction.

Keywords: Dental education, clinical competence, prosthodontics

*This study was presented as an oral presentation summary at the 28th Turkish Dental Association International Dental Congress on September 18-21, 2025.

INTRODUCTION

The focus of dental education is to provide students with the knowledge and skills necessary for effective oral health care and to encourage lifelong professional development so that they can face the challenges of dental practice.[1] All dental professionals are expected to demonstrate competence, empathy, and professionalism in clinical practice to ensure they can provide safe and effective clinical care.[2] Dental education programs worldwide require dental graduates to complete a certain period of clinical practice as part of their training.[3] Dental internships have various purposes and objectives. In particular, they aim to develop general dental knowledge and clinical skills under supervision and to foster greater responsibility among interns in patient care and clinical competence.[4] Dental students must achieve basic competencies during their undergraduate curriculum in accordance with professional standards. Competency in dental education integrates knowledge, skills, attitudes, and character for safe, ethical, and independent practice.[5] A successful prosthetic restoration can only be achieved with the correct diagnosis and treatment plan. The patient's biological systems, the mechanical design of the prosthesis, and the physical compatibility of dental materials play a key role in the success of prosthetic dental treatment.[6] Dental students may experience difficulties in learning prosthetic treatment procedures due to various reasons, such as the large number of treatment sessions and the need for collaboration with dental technicians. This situation can cause stress for both patients and students.[7,8] It is important for dental students to be aware that such situations are part of dental education and practice and to develop problem-solving skills in these situations.[9]

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Dental students complete their internships alongside research assistants in the Department of Prosthodontics. All dental procedures are subject to the approval of the research assistants and responsible faculty members. Dental students enhance their theoretical and practical knowledge by benefiting from the expertise and skills of both research assistants and faculty members in the field of prosthodontics.[10,11]

Fırat University's dental medicine undergraduate program includes three years of preclinical study and two years of clinical practice. This study aims to identify the treatment, planning, and X-Ray evaluation skills of 4th- and 5th-year dental students and newly graduated doctors from our faculty, as well as the procedures they find challenging in the clinical stages of fixed and removable prostheses. There are studies in the literature that examine the clinical competence and knowledge levels of dental students; however, studies evaluating prosthodontic internship experiences according to class level are quite limited.

It was hypothesized that increasing clinical experience would enhance procedural efficiency, confidence, and empathy in prosthodontic treatments, while specific stages such as occlusal adjustment and removable partial denture planning would remain challenging regardless of experience level.

METHODS

The study was approved by the Fırat University Non-interventional Researches Ethics Committee (Date: 24.04.2025, Decision No: 2025/06-22). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki. Participation in the study was voluntary. A total of 140 dental students and dentists participated in the study, including 55 fourth-year and 45 fifth-year students who had completed their prosthetic dentistry internships at Fırat University Faculty of Dentistry, and 40 recent graduates from our faculty. A 27-question survey form was created via Google Forms to evaluate the clinical internship experiences of the dentists, and the survey link was shared with the participants themselves. An informed consent question was added to the electronic survey, and each participant agreed to participate in the survey.

The form contained 5-point Likert-type questions that could be answered as "strongly disagree, disagree, undecided, agree and strongly agree" to assess whether students felt competent when planning treatment, evaluating X-Rays, selecting the correct porcelain shade, and performing metal-dentin trials. In addition, our survey included closed-ended questions about the most challenging clinical and laboratory procedures for fixed and removable prostheses, the duration of tooth preparation and impression taking, and the difficulties encountered during the trial phase. Furthermore, the form included comprehensive questions on the ideal treatment approach, patient-dentist communication, and anxious patient management.

Before distribution, the questionnaire was pretested on a group of 10 dental students to ensure clarity and comprehensibility. The collected data were analyzed using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY, USA). Chi-square test and Bonferroni correction were applied where appropriate, and a significance level of $p < 0.05$ was considered statistically significant.

RESULTS

A total of 140 participants were included in the study: 55 fourth-year students, 45 fifth-year students, and 40 recent graduates.

The time spent on single tooth preparation showed significant differences based on students' clinical experience levels (p=0.001, Cramer's V=0.38). Half of the graduates (50.0%) completed the procedure in 15 minutes, while the majority of 5th-year students (56.3%) and most 4th-year students (50.9%) chose the 15-30-minute range. While 30.9% of 4th-year students reported spending 30-60 minutes, this rate decreased to 8.3% among 5th-year students and 10.0% among graduates (**Table**).

There was also a significant difference in responses to the statement "The patient's anxiety affects me" (p=0.027, Cramer's V=0.26). The "strongly agree" response was highest among 5th graders (43.8%), while this rate dropped to 20.0% among 4th graders. The "undecided" (23.6%) and "disagree" (25.5%) responses were more common among 4th-year students, while graduates showed a more balanced distribution between these two extremes (**Table**).

The most challenging complete denture clinical procedure showed significant differences according to experience level (p=0.002, Cramer's V=0.42). Overall, occlusion adjustment was reported as the most frequently challenging step (34.3%). However, the most challenging procedure was reported as try-in denture (43.8%) among 5th-year students, occlusion adjustment was the most common procedure (30.9%) followed by a second impression with eugenol (23.6%) among 4th-year students and occlusion adjustment (50.0%) among graduates (**Table**).

The most common type of failure in metal substructure trials shows statistically significant differences between different clinical groups (p=0.020, Cramer's V=0.24). Fifth-year students most frequently encountered imbalance (41.7%), while fourth-year students most frequently encountered metal seating on the gingiva (32.7%), and graduates most frequently encountered marginal gaps (32.5%) (**Table**).

The most challenging part of removable partial denture planning showed significant differences between groups (p=0.027, Cramer's V=0.29). Although planning appropriate for the patient (rest, claps, etc.) was reported as the most challenging part in all groups, tooth arrangement (27.3%) was reported at relatively higher rates among 4th-year students, framework trial (18.8%) among 5th-year students, and the final session (22.5%) among graduates (**Table**).

The positive response (agree+strongly agree) to the statement "I can perform X-Ray evaluations considering prosthetic factors" was 89.6% (62.5+27.1) in the 5th grade, 85.0% (65.0+20.0) in graduates, and 85.5% (58.2%+27.3%) among graduates in the 4th grade, with no significant difference found between the groups (p=0.339) (**Table**).

Additionally, when examining their responses to the statement "I do not find it difficult to plan removable partial dentures," 43.8% of fifth-year students responded "I agree," the highest rate among graduates was 40.0% responding "I agree," and among fourth-year students, the highest rate was 43.6% responding "I am undecided." The chi-square analysis revealed no statistically significant difference between the groups (p=0.563) (**Table**).

Table. Comparison of responses by academic level for key clinical competencies and procedural challenges (n=140)

	4th year (%)	5th year (%)	Graduate (%)	p*
I have no difficulty planning prosthetic treatment for patients and can vary the treatment.				
I'm undecided	32.7	14.6	17.5	0.054
I agree	50.9	68.8	67.5	
I disagree	7.3	0	0	
I strongly agree	9.1	14.6	15	
I strongly disagree	0	2.1	0	
I can perform X-Ray evaluations, taking prosthetic factors into consideration.				
I'm undecided	12.7	4.2	12.5	0.339
I agree	58.2	62.5	65	
I disagree	1.8	6.3	0	
I strongly agree	27.3	27.1	20	
I strongly disagree	0	0	2.5	
In a single session, I can perform border molding for both maxillary and mandibular complete dentures and make final impressions using zinc oxide-eugenol.				
I'm undecided	30.9	2.1	12.5	0.000
I agree	47.3	58.3	40	
I disagree	16.4	10.4	15	
I strongly agree	3.6	29.2	32.5	
I strongly disagree	1.8	0	0	
How much time do you spend preparing a single tooth?				
15 minutes	18.2	35.4	50	0.001
15-30 minutes	50.9	56.3	35	
30 minutes-1 hours	30.9	8.3	10	
1-2 hours	0	0	5	
I know which parameters to evaluate in fixed prosthetic treatment trials.				
I'm undecided	12.7	4.2	2.5	0.378
I agree	70.9	79.2	82.5	
I disagree	1.8	0	0	
I strongly agree	14.5	16.7	15	
I strongly disagree	0	0	0	
I can solve the problems I encounter in fixed prosthetic treatment trials myself.				
I'm undecided	40	37.5	32.5	0.399
I agree	43.6	52.1	55	
I disagree	10.9	2.1	2.5	
I strongly agree	5.5	8.3	10	
I strongly disagree	0	0	0	
I can easily choose the right color tone.				
I'm undecided	10.9	27.1	20	0.206
I agree	76.4	52.1	67.5	
I disagree	1.8	2.1	2.5	
I strongly agree	10.9	18.8	7.5	
I strongly disagree	0	0	2.5	
I don't have any trouble planning removable partial dentures.				
I'm undecided	43.6	41.7	32.5	0.563
I agree	32.7	43.8	40	
I disagree	18.2	8.3	15	
I strongly agree	5.5	6.3	10	
I strongly disagree	0	0	2.5	
I come to the clinic after conducting preliminary research on pre-treatment procedures.				
I'm undecided	16.4	10.4	22.5	0.709
I agree	60	60.4	45	
I disagree	5.5	8.3	7.5	
I strongly agree	18.2	16.7	22.5	
I strongly disagree	0	2.1	0	

Table. Comparison of responses by academic level for key clinical competencies and procedural challenges (n=140) (continued)

	4th grade (%)	5th grade (%)	Graduated (%)	p*
I feel responsible for the patient I have started treating.				
I'm undecided	1.8	0	0	0.301
I agree	20	35.4	22.5	
I disagree	0	2.1	0	
I strongly agree	78.2	62.5	77.5	
I strongly disagree	0	0	0	
The patient's anxiety affects me too.				
I'm undecided	23.6	12.5	10	0.027
I agree	30.9	29.2	27.5	
I disagree	25.5	8.3	17.5	
I strongly agree	20	43.8	35	
I strongly disagree	0	6.3	10	
I know how to approach an anxious and excited patient.				
I'm undecided	18.2	29.2	30	0.263
I agree	69.1	50	50	
I disagree	3.6	2.1	0	
I strongly agree	9.1	18.8	20	
I strongly disagree	0	0	0	
I have difficulty communicating with patients.				
I'm undecided	14.5	14.6	17.5	0.845
I agree	5.5	10.4	10	
I disagree	67.3	60.4	55	
I strongly agree	0	2.1	0	
I strongly disagree	12.7	12.5	17.5	
I know what I need to do to communicate better with the patient.				
I'm undecided	12.7	14.6	25	0.513
I agree	70.9	64.6	62.5	
I disagree	1.8	0	0	
I strongly agree	14.5	20.8	12.5	
I strongly disagree	0	0	0	
My theoretical knowledge is sufficient for practical applications.				
I'm undecided	47.3	41.7	57.5	0.136
I agree	29.1	43.8	32.5	
I disagree	21.8	10.4	5	
I strongly agree	0	4.2	5	
I strongly disagree	1.8	0	0	
I can easily decide on a post and core indication for a tooth that has undergone endodontic treatment.				
I'm undecided	25.5	16.7	5	0.092
I agree	56.4	60.4	75	
I disagree	5.5	2.1	0	
I strongly agree	12.7	20.8	20	
I strongly disagree	0	0	0	
I can easily decide on the type of occlusion that is appropriate according to the treatment plan.				
I'm undecided	52.7	47.9	45	0.281
I agree	25.5	29.2	37.5	
I disagree	16.4	6.3	5	
I strongly agree	1.8	12.5	10	
I strongly disagree	3.6	4.2	2.5	
I have sufficient knowledge about the differences between the concepts of bilateral balanced occlusion and unilateral balanced occlusion.				
I'm undecided	29.1	16.7	37.5	0.423
I agree	52.7	52.1	42.5	
I disagree	9.1	10.4	5	
I strongly agree	5.5	16.7	12.5	
I strongly disagree	3.6	4.2	2.5	

Table. Comparison of responses by academic level for key clinical competencies and procedural challenges (n=140) (continued)

	4th grade (%)	5th grade (%)	Graduated (%)	p*
I know what to do in case of imbalance with fixed prostheses.				
I'm undecided	18.2	8.3	15	0.470
I agree	69.1	64.6	67.5	
I disagree	1.8	2.1	0	
I strongly agree	10.9	25	17.5	
I strongly disagree	0	0	0	
I find the metal testing stage more challenging than the dentin testing stage.				
Yes	30.9	20.8	25	0.502
No	69.1	79.2	75	
I consider the dentin trial phase more challenging than the metal trial phase.				
Yes	52.7	66.7	62.5	0.332
No	47.3	33.3	37.5	
Mark the most challenging fixed prosthesis clinical procedures				
Metal and dentin try-in	25.5	29.2	30	0.068
To make a dental stone model	3.6	2.1	0	
Temporary crown fabrication	10.9	12.5	2.5	
Taking a bite registration	21.8	8.3	27.5	
Crown or bridge removal	16.4	20.8	17.5	
Placing retraction cord	7.3	6.3	10	
Taking impressions with silicone	9.1	0	0	
Color selection	0	0	0	
Mark the most challenging full denture clinical procedure				
Border Molding	9.1	16.7	12.5	0.002
Tooth arrangement	20	43.8	12.5	
Determining the vertical dimension	16.4	12.5	12.5	
Taking a second impression with eugenol	23.6	2.1	10	
Adjusting the occlusion	30.9	25	50	
Taking the first impression with alginate	0	0	2.5	
What is the most difficult stage in tooth preparation?				
Prepare parallel to each other in multiple member sections	32.7	31.3	37.5	0.129
Set the entry path	12.7	41.7	17.5	
Undercut-free cut	18.2	8.3	10	
To avoid damaging the gums	18.2	10.4	12.5	
Create the ideal convergence (conicity) angle	5.5	4.2	5	
Approximal area section	10.9	4.2	15	
Incisal occlusal reduction	1.8	0	2.5	
What is the most common failure you encounter in metal testing?				
Imbalance	20	41.7	25	0.020
Insufficient space for porcelain	27.3	27.1	20	
Rotation of the crown prosthesis	1.8	2.1	5	
Gap at the marginal edge	18.2	4.2	32.5	
Metal seating on the gum	32.7	25	17.5	
What is the most common error you encounter in dentin tests?				
Early occlusal contacts at closure	67.3	77.1	72.5	0.601
Prosthesis not fitting due to proximal contacts	5.5	4.2	5	
Aesthetic issues	9.1	2.1	10	
Inability to achieve gingival-prosthesis margin adaptation	12.7	14.6	5	
Prosthesis fitting due to swelling of the body bases	5.5	2.1	5	
What is the most challenging part of planning removable partial dentures?				
Plan the appropriate prosthesis for the patient (clasps, rest, etc.)	30.9	39.6	27.5	0.027
Tooth arrangement	27.3	16.7	20	
Adjust the vertical dimension	21.8	4.2	10	
Prepare the appropriate clasp seats on the abutment teeth for the removable prosthesis	3.6	12.5	12.5	
Framework trial	9.1	18.8	7.5	
Final fitting session	7.3	8.3	22.5	
Take an impression with alginate for the prosthesis framework	0	0	0	

DISCUSSION

This survey-based project aimed to gain insight into dental students' confidence in performing prosthetic treatments and to evaluate their perceptions of the quality of prosthetic education. The literature contains numerous studies on dental students' clinical competence and knowledge levels. There are also studies in which students evaluate their own treatments and compare clinical education.[12-18] However, studies evaluating prosthetic internship experiences by class are rare. In studies on similar topics conducted by others, methodological approaches vary, making it difficult to compare results. Furthermore, since each institution has specific disciplinary content and learning styles, it is not possible to generalize the findings of a particular dental school. The majority of graduates reported completing a single tooth preparation in "15 minutes." In the fourth year, "30 minutes to 1 hour" was the most frequently reported time, while the "15 minutes" option was rarely mentioned. These results demonstrate that clinical experience significantly affects the duration of the procedure. These findings are supported by studies conducted by Altan et al.[14] and Maskey et al.[19] to increase experience, it may be beneficial to extend the duration of dental preparation procedures during the preclinical phase for students. Additionally, it is recommended that students be monitored and supervised more frequently by faculty members and research assistants during prosthetic procedures they find challenging (**Figure 1**).

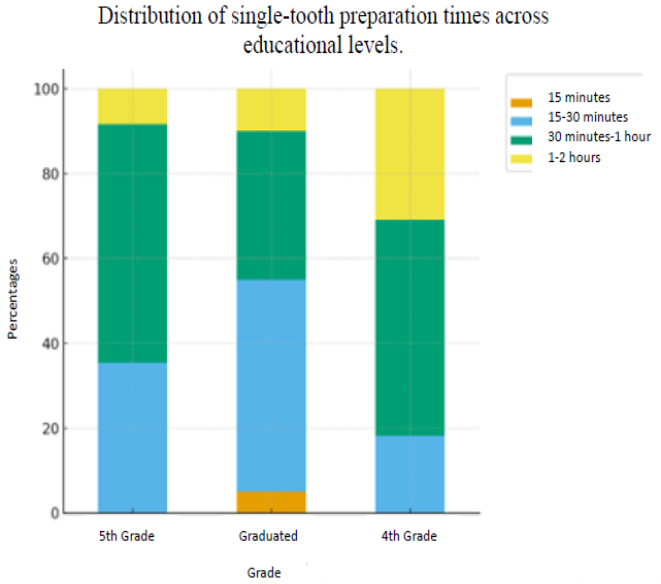

Figure 1. Distribution of single-tooth preparation times across educational levels

Fifth-grade students overwhelmingly agreed with the statement "The patient's anxiety affects me too," while fourth-grade students' responses to this statement showed a wide range of answers. Fourth- and fifth-grade students' perceptions of patient anxiety reflect different stages of their professional development. The lack of clinical experience among fourth graders leads to patient anxiety being perceived as less of a stress source, while increased experience and responsibility among fifth graders strengthens the perception of patient anxiety as a significant stress factor. This situation shows that as students develop their clinical skills, their empathetic responses also increase, and this empathy affects their stress levels (**Figure 2**).

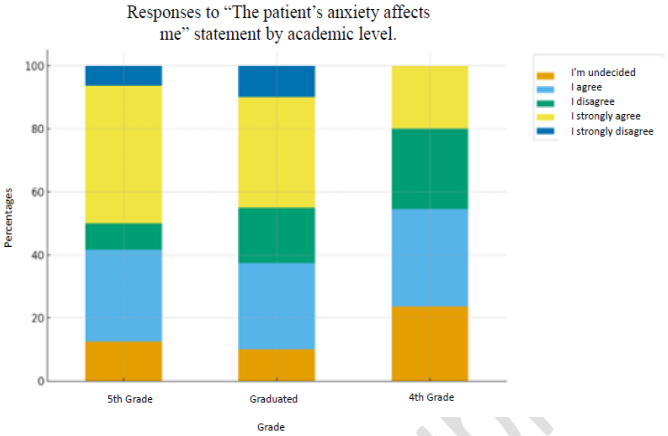

Figure 2. Responses to "the patient's anxiety affects me" statement by academic level

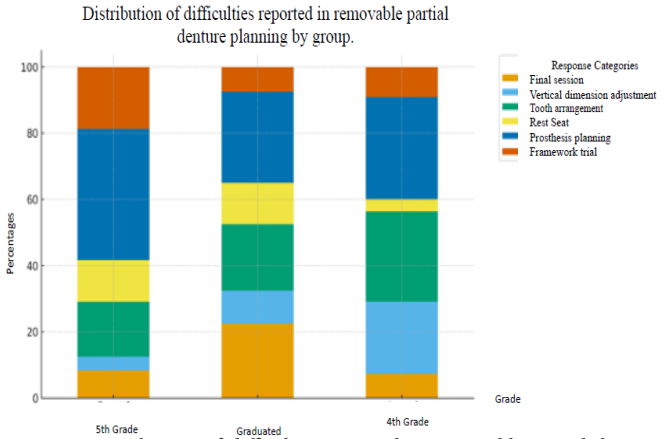

Figure 4. Distribution of difficulties reported in removable partial denture planning by group

The difficulties encountered in complete denture fabrication show significant differences depending on the level of clinical experience (p=0.002). Our study reveals that inexperienced fourth-year students struggle more with impression techniques and occlusion adjustment, while fifth-year students experience more problems in the stages of tooth arrangement and aesthetic adaptation. However, the fact that occlusion adjustment stands out as the most challenging step in a high percentage of 50% among graduate dentists emphasizes that this stage remains difficult even with experience and is one of the most critical and persistent challenges in complete denture treatment. These findings indicate the need for greater focus on occlusion and functional adaptation in prosthodontic education (**Figure 3**).

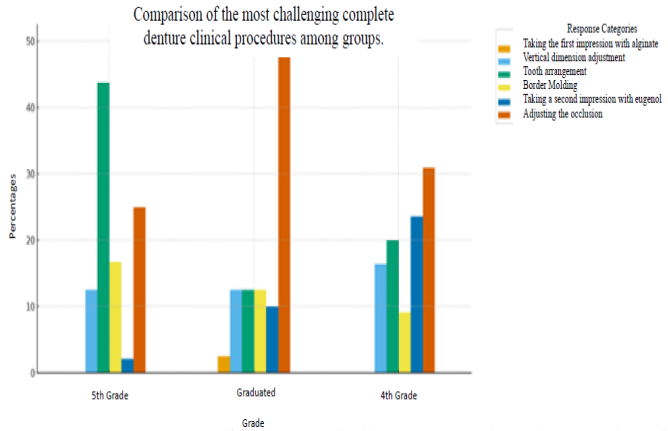

Figure 3. Comparison of the most challenging complete denture clinical procedures among groups

The challenges in planning removable partial dentures vary with clinical experience (p=0.027), but overall, planning that is appropriate for the patient stands out as the most challenging step. As supported by the study by Batak et al.,[16] students are particularly deficient in identifying critical components such as indirect retainers and minor connectors. This situation, combined with difficulties in stages such as tooth arrangement in 4th-year students and framework trials in 5th-year students, shows that each experience level struggles with a different focus. The fact that the final session is a relatively high source of difficulty for graduates emphasizes that the final fit and patient satisfaction stage of the prosthesis remains important even with experience. These findings highlight the importance of planning details and the clinical completion stage in removable partial denture education (**Figure 4**).

Limitations

In this study, certain limitations should be acknowledged. The cross-sectional design of the study limits the interpretation of a causal relationship between experience level and competence. Additionally, the sample was obtained from a single institution, which may restrict the generalizability of the results to other dental schools. Moreover, due to the scarcity of comparable studies in the literature, the scope of discussion-based comparisons was limited. Future multi-center and longitudinal studies with objective performance assessments are recommended to validate these findings and to explore in greater depth the factors influencing clinical competence in prosthodontics.

CONCLUSION

This study revealed that increasing clinical experience among dental students leads to shorter procedure times, improved clinical confidence, and enhanced empathy in prosthodontic practice. However, certain challenges particularly occlusal adjustment in complete dentures and treatment planning in removable partial dentures persist regardless of experience level. To address these difficulties, prosthodontic education should place greater emphasis on occlusal analysis and planning exercises within both preclinical and clinical training. Providing greater guidance during complex clinical procedures and emphasizing case-based applications in clinical training may contribute to the development of students' clinical competence, communication, and decision-making skills.

ETHICAL DECLARATIONS

Ethics Committee Approval

The study was carried out with the permission of the Fırat University Non-interventional Researches Ethics Committee (Date: 24.04.2025, Decision No: 2025/06-22).

Informed Consent

All participants signed an open and informed consent form.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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Dental students' perceptions of specialty training and career choice

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ABSTRACT

Aims: The aim of this study is to evaluate dental school students' views on postgraduate specialty training and to examine the effect of their academic career plans on their choice of specialty.

Methods: This cross-sectional study was conducted with students enrolled in a dental school during the 2024-2025 academic year. Ethical approval was obtained from the Dicle University Faculty of Dentistry Ethics Committee (Date: 29.11.2023, Decision No: 2023-41). A total of 458 students voluntarily responded to the online questionnaire, which consisted of 14 questions. The data were evaluated using descriptive and comparative statistical analyses with the SPSS (version 25.0) program.

Results: Preclinical students comprise 52.3% of the participants, while clinical students comprise 47.7%. More than half had already heard of the concept of specialty training before entering dental school, and the vast majority agreed that specialty training is necessary in dentistry. The most preferred specialty area was oral and maxillofacial surgery (38.6%). 88% of participants stated that they plan to pursue specialty training after graduation. The most frequently cited reasons for pursuing specialty training were professional development (27.2%), financial gain (13.2%), academic career goals (11.3%), and personal interest (10.5%). While some differences were found based on educational level, no differences were observed based on gender ($p>0.05$).

Conclusion: This study demonstrates that dental students are highly motivated regarding their specialty training and career plans. The timing of specialty awareness and the reasons for preference indicate that informative and guiding activities should be increased throughout undergraduate education to enable students to make more informed career choices.

Keywords: Students, dental, specialties, dental, career choice, education, dental

INTRODUCTION

In our country, postgraduate education prior to the Dental Specialty Exam (DUS) was conducted through doctoral programs. Dental specialization in Turkiye gained a legal framework with the enactment of Law No. 6225, published in 2011, and was divided into the following specialties; oral and maxillofacial surgery, oral and maxillofacial radiology, pediatric dentistry, endodontics, orthodontics, periodontology, prosthetic dentistry, and restorative dentistry.[1] With a new decision taken in 2018, Oral Pathology has been officially recognized as the 9th specialty.[2] Since 2012, candidates for specialization in dentistry have been selected through the Dentistry Specialization Exam (DUS), and they are placed in faculty quotas according to their success rankings. The departments of oral and maxillofacial surgery, orthodontics, and oral pathology have a 4-year training period, while other specialties have a 3-year training period. Specialty students receive the title of specialist in their field after completing the required training, rotations, and a successful thesis during this period.[3]

Although general dentistry meets the needs of most patients, difficult and high-risk cases require more advanced knowledge and experience, necessitating the involvement of specialist dentists in such situations.[4] Since specialization in healthcare is associated with efficiency, this trend also applies to dentistry. In recent years, the increase in complex treatment procedures and rising aesthetic expectations have increased the need for dentists who can perform more comprehensive clinical procedures on patients and keep up with developments in the field. These developments have made specialist training mandatory in rare cases that exceed the clinical skills of general practitioners.[5,6]

Students' specialty choices are shaped not only by clinical skills but also by many socio-demographic and personal factors. Studies have reported that elements such as social status, higher financial income, academic career goals, personal interests, opportunities to work abroad, individual work opportunities, and professional satisfaction influence specialty decisions.[7-10] Factors such as working hours, financial benefits, job security, social prestige, and having relatives who are dentists in the family are also considered important.[11-13] It has also been emphasized that motivations for specialization may differ between male and female students, with women

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showing less preference for certain fields.[14,15] At the same time, general practitioners' clinical experiences, concerns about future malpractice lawsuits, and post-specialization employment opportunities also influence decision-making mechanisms.[16]

When reviewing studies conducted in our country in the literature, there are studies that examine post-graduation career plans, as well as studies that evaluate perspectives on the specialties of prosthetic dentistry, restorative dentistry, pediatric dentistry, endodontics, and orthodontics.[7-10,16-22] Upon reviewing these studies, the question of which specialty an undergraduate student with an academic career plan will choose cannot be fully answered. Furthermore, a review of existing studies reveals that the specialty of Oral Pathology has not been examined in these studies. The aim of this study is to address these gaps in the literature.

METHODS

This research was approved by the Dicle University Faculty of Dentistry Ethics Committee (Date: 29.11.2023, Decision No: 2023-41). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki. All dentistry students enrolled at our faculty during the 2024-2025 academic year were invited to participate in the study on a voluntary basis. The data for the study were obtained using a survey method, and the prepared survey form was distributed to students via the internet (e-mail, WhatsApp, etc.).

The sample size was calculated using the G*power 3.1.9.7 program. Based on a 95% confidence level (1-α), 95% test power (1-β), and an effect size of d=0.2005251, it was decided that the study would be conducted with a total of 390 participants. Due to higher-than-expected participation in the survey, the study was completed with 458 participants.

The survey consisted of 14 questions. The first three questions of the survey were demographic questions, such as age, gender, and education period. The remaining 11 questions were designed to inquire about the students' thoughts on their specialist training and exam (**Table**).

Statistical Analysis

The normality of continuous variables was assessed using the Shapiro-Wilk test. Variables showing a normal distribution were expressed as mean±standard deviation, while those not conforming to normal distribution were presented as median (minimum: maximum). Categorical variables were reported as frequencies and percentages [n (%)].

According to the results of the normality test, comparisons between two independent groups were performed using the Mann-Whitney U test. When the number of groups exceeded two and normal distribution was not observed, the Kruskal-Wallis test was applied. In cases where the Kruskal-Wallis test indicated overall significance, post-hoc pairwise comparisons were conducted using the Dunn-Bonferroni test.

Categorical variables were compared between groups using the Chi-square test or the Fisher-Freeman-Halton test, as appropriate. Statistical analyses were performed using SPSS software (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.), and a p-value of <0.05 was considered statistically significant.

Table. Investigating dental school students' thoughts on specialty training and the impact of their academic career plans on their choice of specialty

1. What is your gender?
Female
Male
2. Your age?
……..
3. What is your level of education?
1st year preclinical student
2nd year preclinical student
3rd year preclinical student
4th year clinical student
5th year clinical student
4. When did you first hear about specialization training in dentistry?
Before university
During university selection period
Preclinical period
Clinical observation period
Clinical period
5. Which was the first specialty area you heard about?
Oral and maxillofacial surgery
Oral and maxillofacial radiology
Restorative dentistry
Prosthodontics
Endodontics
Periodontology
Orthodontics
Pediatric dentistry
Oral pathology
6. Do you think specialization training in dentistry is necessary?
Yes
No
7. If your answer to Question 6 is 'Yes,' in which field do you think specialization is most necessary?
Oral and maxillofacial surgery
Oral and maxillofacial radiology
Restorative dentistry
Prosthodontics
Endodontics
Periodontology
Orthodontics
Pediatric dentistry
Oral pathology
All
8. What is your opinion about the Dentistry Specialization Examination (DUS)?
Positive
Somewhat positive
Neutral
Somewhat negative
Mostly negative
9. When choosing dentistry as a profession, did you plan to receive specialization training?
Yes
No
10. Are you currently considering pursuing postgraduate specialization training?
Yes
No

Table. Investigating dental school students' thoughts on specialty training and the impact of their academic career plans on their choice of specialty (continued)
11. If your answer to Question 10 is 'Yes,' which field do you aim to specialize in?
Oral and maxillofacial surgery
Oral and maxillofacial radiology
Restorative dentistry
Prosthodontics
Endodontics
Periodontology
Orthodontics
Pediatric dentistry
Oral pathology
12. For what reason(s) would you like to receive specialization training? (You may select more than one option.)
To pursue an academic career
Because of my personal interest in the specialty
To improve myself professionally
For better financial opportunities after graduation
To enhance my social status
For more flexible working hours
To be my own boss
Other
13. If your goal after specialization is to continue academically, which department would you prefer?
Oral and maxillofacial surgery
Oral and maxillofacial radiology
Restorative dentistry
Prosthodontics
Endodontics
Periodontology
Orthodontics
Pediatric dentistry
Oral pathology
14. If your expectation from specialization training is better financial income, which department would you prefer?
Oral and maxillofacial surgery
Oral and maxillofacial radiology
Restorative dentistry
Prosthodontics
Endodontics
Periodontology
Orthodontics
Pediatric dentistry
Oral pathology

RESULTS

Of the 458 participants in the survey, 241 were female (52.6%) and 217 were male (47.4%). The average age of the participants was determined to be 21.61±2.98 years.

The students' distribution was nearly evenly split between preclinical and clinical stages (**Figure 1**).

Approximately 59.8% of participants reported prior awareness of dental specialty training before commencing their university education. A total of 35.4% of participants indicated that orthodontics was the first dental specialty they had heard of, followed by oral and maxillofacial surgery (30.8%). Less well-known fields included oral and maxillofacial radiology (0.7%) and oral pathology (0.2%).

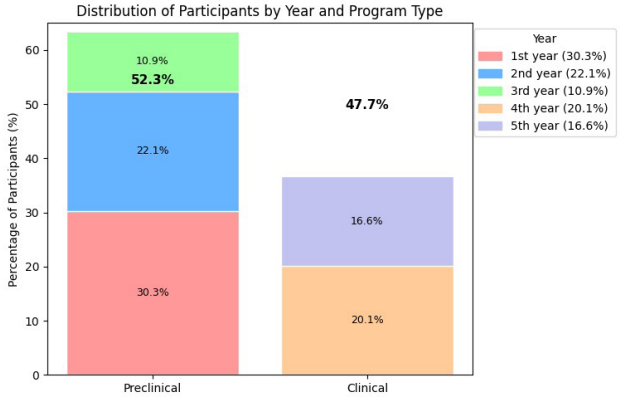

Figure 1. Distribution of participants according to academic year

Among the individuals participating in the study, there was a significant difference between the answers to the question "When did you first hear about specialty training?" and the level of education ($p<0.001$). In particular, the vast majority of first-year preclinical students stated that they were aware of specialty training before starting university. This suggests that awareness of specialty training in society is increasing.

When asked, "Do you think specialty training is necessary in dentistry?" the vast majority of students agreed that specialization is necessary in dentistry. Significant differences by educational level were found regarding which branches were perceived as most essential ($p=0.001$), with fifth-year students showing greater recognition of oral pathology as a critical specialty (**Figure 2**).

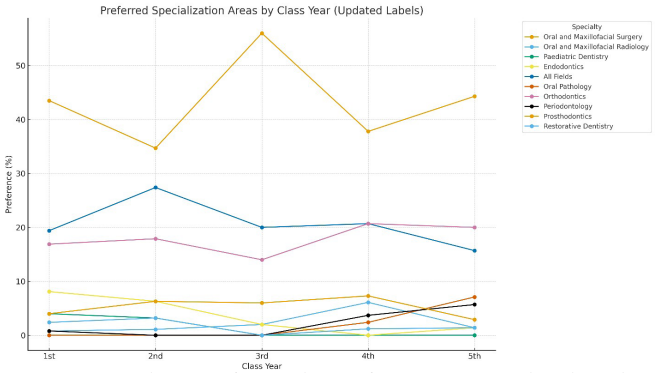

Figure 2. Distribution of specialty preferences among dental students according to academic year

When examining opinions about the DUS, 49.6% of participants reported a positive opinion, while 25.8% reported a partially positive opinion. This situation is thought to reflect a general satisfaction with the DUS. The fact that 19.9% of participants were undecided about the DUS indicates that there needs to be more information and discussion on this subject. The percentage of those who were mostly negative was quite low, at 2%.

When examining specialty training plans while choosing dentistry, it is seen that 71% of participants planned to pursue specialty training while choosing dentistry. This rate suggests that a significant number of students consider pursuing advanced education when entering the profession. The rate of those who answered "no" is 28.8%. Upon examining the results, a significant difference was found between educational

level groups (p<0.001). It was determined that first-year preclinical students had a higher rate of planning to pursue specialty training when choosing dentistry. In response to the question of whether they planned to pursue a specialty when choosing dentistry, a higher percentage of female students indicated that they planned to pursue a specialty (p=0.047).

It is observed that 88% of participants plan to pursue postgraduate specialty training after graduation. This indicates that students are highly motivated to continue their education at a more advanced level. The percentage of those who answered "no" remained at 12%, highlighting that specialty training is viewed as an important step for professional development. A significant difference was also found between educational level groups in responses regarding the intention to pursue post-graduation specialization (p=0.006). In this context, second-year preclinical students were found to have a higher rate of considering post-graduation specialized training. No significant difference was found in responses regarding the intention to pursue postgraduate specialization based on gender (p=0.087).

When examining the specialty areas preferred by students planning to pursue a specialty after graduation, oral and maxillofacial surgery (34.3%) and orthodontics (27.9%) are the most popular fields among those wishing to pursue specialty training. Less preferred fields include oral and maxillofacial radiology (1.5%), periodontology (1.3%), and oral pathology (0.7%). It was determined that the proportion of 5th-year students preferring periodontology and 2nd-year preclinical students preferring restorative dentistry was higher (p<0.001). No significant difference was found among other groups (p>0.005). No significant difference was found in the responses regarding the fields that students considering postgraduate specialization would choose based on gender, and this difference was determined to be statistically insignificant (p=0.137).

It is observed that 27.2% of participants wish to pursue specialized training to advance their careers, 13.2% to achieve better financial opportunities after completing their education, and 11.3% to pursue an academic career. In addition, 10.5% of participants stated that they preferred this training because of their special interest in their field of expertise, while 4.2% stated that they wanted to be their own boss. Among participants with multiple motivations, those aiming for an academic career, interest in their field of expertise, and professional development together accounted for 2.2%; those seeking professional development, improved financial opportunities, and social status accounted for 2.0%; and those aiming for an academic career, professional development, and improved financial opportunities accounted for 1.7%. Additionally, 1.7% of participants preferred more flexible working hours. Beyond this, 1.5% aimed solely for an academic career and professional development, 1.5% considered an academic career, professional development, and financial improvement together, and 1.5% sought to raise their status in society. Finally, 1.2% of participants stated that they aimed for an academic career, interest in their field of expertise, and professional development. 20.3% of participants indicated that they wanted to receive specialist training, citing multiple motivations.

When examining academic career preferences, the most preferred fields for those aiming for an academic career are oral and maxillofacial surgery (35.2%) and orthodontics (24%). the least preferred academic fields are oral and maxillofacial radiology (2.6%), oral pathology (1.5%), and periodontology (0.9%). When the results were examined, it was seen that the proportion of second-year students was higher among those who preferred the field of restorative dentistry (p<0.001). No significant difference was found among other groups (p>0.005). No significant difference was observed between gender groups in the responses regarding the departments that students planning to pursue an academic career after specialty training would choose (p=0.126).No significant difference was found between gender groups in the responses regarding the departments that students expecting economic gain from specialty training would choose (p=0.649) (**Figure 3**).

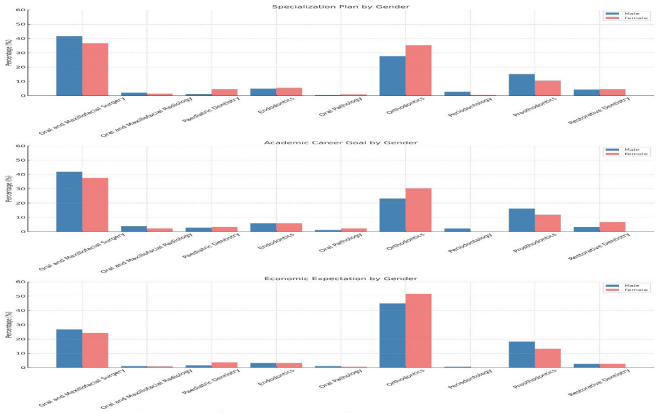

Figure 3. Distribution of specialty preferences, academic career goals, and economic expectations by gender

When examining specialty preferences based on economic motivations, Orthodontics is the most preferred field due to expectations of better economic gains (43%). This indicates that orthodontics is perceived as having high economic potential alongside its popularity. Oral and maxillofacial surgery (22.5%) ranks second in terms of economic motivation. Among the less preferred fields are oral pathology (0.7%) and periodontology (0.2%). When examining the departments preferred by students whose expectation from specialty training is to achieve better economic gains, it was found that the proportion of third-year preclinical and fourth-year clinical students was higher among those who preferred Orthodontics (p=0.002). No significant difference was found among other groups (p>0.005).

DISCUSSION

Of the 458 dental students participating in this study, 52.3% were preclinical students and the remaining 47.7% were clinical students, with an average age of 21.61±2.98 years. A significant proportion of students (59.8%) stated that they were familiar with the concept of specialty training in dentistry before starting university. This indicates that the proportion of students hearing about it for the first time during the preclinical period is relatively low. Previous studies in the literature report that most students are introduced to specialty fields during the preclinical education process.

Aksoy et al.[9] found in their study that 75.3% of students first heard about the Prosthodontics department during the preclinical period. Similarly, in a study conducted in the field of endodontics, 69% of participants stated that they first heard about this discipline during preclinical education.[20]

In another study on restorative dentistry, 47% of students reported that they learned about this department through faculty courses.[17] Our study shows that students are now encountering the concept of specialization at an earlier stage, particularly before starting university. This situation indicates that, with the increase in the number of graduates over the years, social awareness of specialty training has increased, and students are becoming knowledgeable about this subject at an earlier age.

It has been observed that opinions regarding the necessity of specialty training in dentistry are quite strong. The vast majority of participants (91.9%) agreed that specialization is essential in the field of dentistry. This finding largely coincides with previous literature. In a study conducted by Çulhaoğlu et al.[19] on the Dentistry Specialization Exam (DUS), 91.5% of preclinical students and 88.7% of clinical students indicated that they were inclined to pursue specialization. Similarly, in a survey on post-graduation career plans conducted by Taşsöker et al.[21] 52.3% of participants responded that they were "considering specialization," emphasizing high motivation for specialization. The findings of our study reveal that the increasing clinical diversity, technological innovations, and multidisciplinary approach in modern dental practice are directing physicians to acquire in-depth knowledge and skills in specific areas.

When participants were asked, "In which field do you think specialized training is most necessary?", the most common response was oral and maxillofacial surgery (38.6%). Meanwhile, 19.2% of participants indicated that specialized training was necessary in all fields, selecting the "all" option. In a study conducted on third-, fourth-, and fifth-year students, similar to our study, participants most frequently indicated the need for specialized training in oral and maxillofacial surgery (43.4%).[7] Similarly, in a study by Erhamza et al.[8] oral and maxillofacial surgery (40.8%) was also considered the most necessary specialty. Our findings largely coincide with those in the literature. The fact that oral pathology was mentioned more frequently by fifth-year students may be related to this specialty becoming more visible and being introduced later in the undergraduate curriculum. This finding reflects the relationship between the content of the undergraduate curriculum and the level of awareness regarding specialties.

In our study, the percentage of participants planning to pursue a specialty when choosing the dentistry department was determined to be 71%, and the results are consistent with the current literature.[19,22] In a study on post-graduation career motivation, oral and maxillofacial surgery ranked first with 33.3%, while orthodontics ranked second with 15.2%.[21] In another survey focusing on the field of pediatric dentistry, oral and maxillofacial surgery was the most preferred specialty, with a rate of 38.8%, while orthodontics was again reported in second place.[7] Similarly, in a study conducted by Gedikli et al.[20] the top two most preferred specialties were oral and maxillofacial surgery (34.2%) and orthodontics (23.6%). The results of our study are consistent with the literature.

When examining the primary motivational factors behind participants' choice of specialty, the most prominent factors were professional development (27.2%), better financial opportunities (13.2%), and the desire to pursue an academic career (11.3%). Our results were consistent with the data in the literature.[16,22] However, 10.5% of participants stated that their preferences were based on their particular interest in the fields of specialization. This distribution largely overlaps with the motivational factors reported in previous literature.[7,9,17] The findings of this study reveal that the motivations guiding students' specialization choices cannot be reduced to a single cause but are shaped by multidimensional reasons. In particular, the high percentage of participants who expressed both professional development goals and expectations of economic gain and social status indicates that students view specialty training not only as professional competence but also as a strategic investment for the future.

In our study, no significant difference was found between educational levels in terms of attitudes toward DUS, plans for specialization, and the necessity of specialized training. This indicates that awareness of specialization is widespread and strong across different class levels.

Overall, the findings of this study are largely consistent with previously reported trends in the literature, supporting the high motivation of dental students regarding specialty training and career plans. However, differences observed in the timing of first exposure to the concept of specialization and in the level of awareness of certain fields reveal that pre-university information activities and undergraduate-level introduction processes are not homogeneous.

Limitations

This study has certain limitations. First, the research was conducted at a single dental faculty, which may limit the generalizability of the results to students from other institutions or regions. Second, the study relied on self-reported data, which could be affected by social desirability bias. Additionally, while the survey covered a wide range of motivational and perceptual factors, it did not include qualitative components such as interviews or open-ended responses, which could have provided a deeper insight into students' reasoning processes. To confirm and expand upon these findings, future multi-center and longitudinal studies using mixed methods are ideally recommended.

CONCLUSION

As a result, the literature and the results of the current study indicate that the factors that influence the specialization preferences of dental students are diverse. Career planning can be facilitated in accordance with the specialty requirements of the national health system by providing early and comprehensive information about specialty examinations and branches. This method will not only assist students in making well-informed and fulfilling career decisions, but it will also guarantee that the oral and dental health requirements of the community are adequately addressed. Moreover, the establishment of structured guidance within dental education could promote a more effective alignment between the demands of specialty and the interests of students, thereby contributing to the development of more effective curriculum and policy in the field of dental education.

ETHICAL DECLARATIONS

Ethics Committee Approval

The study was carried out with the permission of the Dicle University Faculty of Dentistry Ethics Committee (Date: 29.11.2023, Decision No: 2023-41).

Informed Consent

All dentistry students signed an open and informed consent form.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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Enhancing clinical training through understanding patient attitudes toward rubber dam application by undergraduate dental students: a study at a university in Thailand

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ABSTRACT

Aims: This study aimed to determine patient attitudes toward rubber dam use in operative dentistry and identify associated factors among patients treated by undergraduate dental students at Western University, providing evidence-based insights to enhance clinical training strategies.

Methods: This cross-sectional study was conducted from February to December 2024 at the Operative Dentistry Clinic, Faculty of Dentistry, Western University. Data were collected using a closed-ended questionnaire, which included demographic information and experiences with operative dental treatment. Patient attitudes were assessed using an 11-question, five-point Likert scale. Total attitude scores were categorized into negative (1-33), neutral (34-43), and positive (44-55) based on modified Bloom's cut-off criteria.

Results: A total of 98 completed questionnaires consisted of 44.90% males and 55.10% females. The mean attitude score was 40.23±6.53. While most patients (79.6%) expressed a preference for future rubber dam use and recognized its benefits (95.92% for foreign body aspiration prevention; 91.84% for moisture control), their attitudes were primarily neutral (72.4%). Ordinal regression analysis showed that only the duration of the presence of the rubber dam significantly influenced patient attitude (p=0.016), with a 1-min increase associated with a 2.2% decrease in the odds of a more positive attitude (odds ratio=0.978, 95% confidence interval: 0.961-0.996). No significant association was found between gender, age, local anesthesia, prior experience, and explanation of benefits.

Conclusion: Based on the limitations of this study, the findings indicate the need for dental student training focusing on improving time management and patient comfort during rubber dam application to enhance patient satisfaction and acceptance.

Keywords: Dental students, operative dentistry, patient attitude, rubber dam isolation

INTRODUCTION

The application of rubber dam isolation in restorative dentistry is paramount for clinical efficacy and patient safety.[1] It is considered the gold standard for adhesive restorative treatments because it provides effective moisture control, which is crucial for material bonding and restoration longevity.[2] Beyond moisture control, the rubber dam improves patient safety by preventing accidental ingestion or aspiration of instruments and materials while also protecting soft tissues from injury; it also improves the operator's visibility and access to the working field. In the context of infection control, its use is vital for reducing aerosol dissemination, a benefit that has been particularly highlighted since the COVID-19 pandemic.[3]

Despite the integral inclusion of rubber dam application in the dental curriculum across dental schools, Gilbert et al.[4] reported that only 12% of tooth restorations were performed with a rubber dam. This limited adoption is frequently attributed to various barriers affecting practitioners and patients.[5,6] The time-consuming and difficult application of rubber dams, which can prolong the treatment duration and increase associated costs, are often mentioned by dentists.[4] Conversely, patients may express discomfort, such as difficulty breathing or gingival pain resulting from clamp pressure, resulting in refusal of its use. Studies among dental students also reflect these concerns. Mala et al.[7] found that 45% of dental students perceived patient dissatisfaction with rubber dam, a finding consistent with other research where 53% of final-year dental students deemed the application procedure complicated and 45% believed patients disliked its use. Despite recognizing its importance, 62% of dental students anticipated a decrease in their own rubber dam use after graduation.

Contrary to these perceived barriers, some patient-centered studies have reported positive experiences. For instance, a previous study in Czech patients indicated that 77% of the patients felt more comfortable when a rubber dam was used.[8] The review literature concluded that practitioner experience influences patient attitudes, whereas patient gender and

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age showed no correlation. Such variations across studies, potentially influenced by differing sociocultural contexts or clinical practices, suggest that geographical factors have an impact on patient attitudes.[9]

Providing enduring recommendations for infection control from aerosols in dental practice, even as the COVID-19 pandemic transitions to an endemic phase, and acknowledging the need for resource efficiency and patient-centric care are crucial. A limited body of research on patient attitudes toward rubber dam use in operative dentistry, particularly in a contemporary and evolving context, remains.

This study aimed to determine patient attitudes toward rubber dam use in operative dentistry and identify associated factors among patients treated by undergraduate dental students at Western University, thereby providing objectively derived insights for evaluation and enhancing clinical training strategies.

METHODS

This study was approved by the Western University Human Researches Ethics Committee (Date: 26.12.2023, Decision No: HE-WTU2566-0112). Thai independently, and providing voluntary informed consent after receiving comprehensive information about the research project before data collection. This study adhered to the principles of the Declaration of Helsinki.

A descriptive, cross-sectional study was conducted using a questionnaire to assess patient attitudes toward rubber dam used in operative treatment performed by undergraduate dental students. This study was conducted at the operative dentistry Clinic, Faculty of Dentistry, Western University. The undergraduate dental program is a full-time, 6-year program that encompasses theoretical instruction, clinical practice, and externship. The study participants were recruited from patients undergoing this operative treatment at the clinic. The operative treatment, including the application of rubber dam, was performed by 5th and 6th-year dental students as part of their clinical training.

Participants were selected based on the following specific inclusion criteria: male or female patients aged 20 years or older, undergoing operative dental treatment necessitating tooth restoration with filling materials under rubber dam isolation, and capable of independently reading and writing Thai. The exclusion criteria included patients under 20 years of age or those unwilling to participate.

The sample size was determined through an a priori sample size calculation with a finite population correction. Based on a known patient population of 124 at the operative dentistry clinic, 95% confidence level, and 5% margin of error, the required sample size to estimate patient attitudes was calculated to be 94. An additional 10% was recruited to account for the potential dropout rate, bringing the final recruitment goal to 103 participants. This methodology ensured that the sample size was adequately powered to provide a precise estimate of patient attitudes within the specific study population.

Data were collected using a closed-ended questionnaire structured into three sections: general demographic information (gender, age, and respiratory conditions), experiences with dental treatment, and attitudes toward rubber dam use in operative dental treatment.

Patient attitudes were assessed using an 11-question Likert scale with five response levels (strongly agree, agree, undecided, disagree, and strongly disagree). Total attitude scores were calculated and subsequently categorized into three groups-negative (score 1-33), neutral (score 34-43), and positive (score 44-55)-based on established scoring criteria derived from modified Bloom's cut-off categories.[10] The content validity of the questionnaire was evaluated by three experts using the Index of Item Objective Congruence (IOC), with questions deemed acceptable if their IOC value ranged between 0.50 and 1.00. Furthermore, a pilot study involving 20 subjects was conducted to determine the reliability of the questionnaire, yielding an acceptable Cronbach's alpha coefficient greater than 0.8. The duration of rubber dam placement and the total duration of rubber dam presence during the treatment procedure were meticulously recorded by an assisting student.

Upon recruitment, the participating patients received detailed information regarding the study objectives and the questionnaire. It was explicitly communicated that participation would not affect the standard of service received at the Faculty of Dentistry, Western University, and that participants retained the right to withdraw at any point. Following the signing of the consent form, the questionnaire was administered to the patient at the conclusion of their treatment.

Patients completed the questionnaire in a designated waiting area to mitigate potential bias from healthcare providers. Only fully completed questionnaires were included in subsequent data analysis.

Statistical Analysis

All collected data were entered into a computer for statistical analysis using the SPSS 22.0 software (SPSS, Chicago, IL, USA). Descriptive statistics were employed to characterize the general attributes of the participants. Continuous variables exhibiting a normal distribution are presented as mean standard deviation. All categorical data are summarized using percentages. Ordinal logistic regression analyses were used to ascertain associations between variables, with a statistical significance level at p-value <0.05.

RESULTS

Participants Characteristics

Out of 101 distributed questionnaires, 98 were successfully completed and included in the statistical analysis; two were excluded because of incomplete data. The study sample consisted of 44 males (44.9%) and 54 females (55.1%). The participant age distribution is detailed in **Table 1**. A small percentage of patients (2.0%) reported pre-existing respiratory conditions.

Main Results

Regarding prior experience with rubber dam application, 55.1% (n=54) of patients reported it as their first experience, whereas 44.9% had previously undergone dental treatment involving a rubber dam. The majority of previous rubber dam use was for restorative treatment (41.8%), followed by endodontic treatment (6.1%) and other dental procedures. Local anesthesia was administered to 23.5% of the patients during treatment, and 76.5% received an explanation of the benefits of rubber dam usage before treatment initiation. The duration of rubber dam placement ranged from 3 to 60 min,

Table 1. General demographic status and patient experiences (n=98)		
Characteristic		**Count (%)**
Gender	Male	44 (44.9)
	Female	54 (55.1)
Age (years)	20-30	29 (29.6)
	31-40	20 (20.4)
	41-50	10 (10.2)
	51-60	25 (25.5)
	>60	14 (14.3)
Respiratory condition	No	96 (98.0)
	Yes	2 (2.0)
Prior experience with rubber dam use	No	54 (55.1)
	Yes	44 (44.9)
Prior treatment involving rubber dam usage		
Operative		41 (41.8)
Endodontic		6 (6.1)
Prosthetic		1 (1.0)
Current experience		
Local anesthesia administration	No	74 (75.5)
	Yes	24 (24.5)
Explanation of benefits before treatment	No	23 (23.5)
	Yes	75 (76.5)

with a mean of 17±10.9 min. The duration of rubber dam presence during treatment ranged from 10 to 150 min, with a mean of 85±27.4 min (**Table 2**).

Table 2. Duration of rubber dam placement and presence			
Duration	**Mean±SD**	**Min (minute)**	**Max (minute)**
Rubber dam placement	17±10.9	3	60
Rubber dam presence	85±27.4	10	150

SD: Standard deviation, Min: Minimum, Max: Maximum

Patient attitude scores toward rubber dam application ranged from 25 to 55 points, yielding a mean score of 40.2±6.5. Based on the predefined scoring criteria, most patients exhibited neutral attitudes (72.4%), with 27.6% holding positive attitudes and 13.3% reporting negative attitudes. A high percentage of patients affirmed the benefits of rubber dam use: 95.9% stated that it prevents foreign body aspiration, and 91.8% indicated that it helps manage intraoral water accumulation. Conversely, the negative statement with the lowest mean score pertained to pain associated with the rubber dam. Notably, 42.9% of the participants agreed that the duration of rubber dam presence in the oral cavity was excessive. Nonetheless, a considerable majority (79.6%) of the patients expressed a preference for rubber dam use in future treatments. All categorical data are summarized using percentages. The response percentages for each Likert item and the total mean±standard deviation (SD) score are presented in **Table 3**.

Ordinal regression analysis showed that, among all factors examined, only the duration of rubber dam presence significantly influenced patient attitude (p=0.016). For every 1-min increase in the duration the rubber dam was present, the odds of a patient reporting a more positive attitude decreased by 2.2% [odds ratio (OR)=0.978, 95% confidence interval (CI): 0.961-0.996]. This indicates that longer durations are significantly associated with less favorable patient perceptions. Conversely, other factors such as gender (p=0.270, OR=1.547), age (p=0.547, OR=0.994), local anesthetic application (p=0.872, OR=0.908), prior experience with rubber dam (p=0.582, OR=0.801), duration of rubber dam placement (p=0.179, OR=1.000), and whether an explanation of benefits was given (p=0.679, OR=1.277) did not show a statistically significant association with patient attitudes in this regression model (**Table 4**). These factors did not significantly change the odds of a patient being in a higher attitude category.

DISCUSSION

The findings of this study revealed that a majority of patients held neutral attitudes (72.4%) toward rubber dam use, with a substantial proportion expressing positive attitudes (27.6%) and a notable percentage reporting negative attitude (13.3%). The ordinal regression analysis showed a significant inverse relationship between the duration of rubber dam presence in the oral cavity and patient attitude scores, indicating that longer durations lead to less favorable patient attitudes. The findings of this study on patient attitudes present agreement

Table 3. Attitudes toward rubber dam usage in percentage and mean±SD score using Likert's Scale analysis							
No.	**Questions**	**Strongly agree**	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**	**Mean±SD**
1	Rubber dam application for dental fillings makes you feel more comfortable during treatment compared with a filling without rubber dam	38.8	37.8	10.2	10.2	3.1	4.0±1.1
2	Rubber dam application causes pain	20.4	19.4	16.3	25.5	18.4	3.0±1.4
3	Rubber dam application makes it uncomfortable or causes breathing difficulty	17.4	17.4	15.31	35.7	14.3	2.9±1.3
4	Rubber dam application causes anxiety due to communication difficulties with the dentist	18.4	20.4	10.2	26.5	24.3	2.8±1.5
5	Procedure of rubber dam placement takes a long time	15.3	23.5	18.4	31.6	11.2	3.0±1.3
6	Duration of rubber dam presence is long	17.4	25.5	20.4	24.5	12.2	3.1±1.3
7	Prefer to receive dental filling treatment with rubber dam application rather than without	30.6	34.7	17.4	6.1	11.2	3.7±1.3
8	Rubber dam application in dental fillings is beneficial for patients	48.0	39.8	9.2	1.0	2.0	4.3±0.8
9	Rubber dam application helps prevent filling materials or foreign objects from falling into the throat area	65.3	30.6	1.0	1.0	2.0	4.6±0.8
10	Rubber dam application prevents water from accumulating in the oral cavity	54.1	37.8	6.1	1.0	1.0	4.4±0.8
11	Prefer to have a rubber dam applied in the next treatment	40.8	38.8	12.2	2.0	6.1	4.1±1.1

SD: Standard deviation

Table 4. Factors associated with attitude toward rubber dam use in the ordinal logistic regression analysis

Factors	Attitude			OR	95% CI	p-value
	Positive n (%)	Neutral n (%)	Negative n (%)			
Gender				1.547	0.717, 3.344	0.270
Male	15 (34.1)	23 (52.3)	6 (13.6)			
Female	12 (22.2)	35 (64.8)	7 (13.0)			
Age (years)				0.994	0.975, 1.013	0.547
20-30	6 (20.7)	18 (62.1)	5 (17.2)			
31-40	7 (35.0)	11 (55.0)	2 (10.0)			
41-50	3 (30.0)	4 (40.0)	3 (30.0)			
51-60	7 (28.0)	16 (64.0)	2 (8.0)			
>60	4 (28.6)	9 (64.3)	1 (7.1)			
Prior experience				0.801	0.389, 1.649	0.582
No	16 (29.6)	30 (55.6)	8 (14.8)			
Yes	11 (25.0)	28 (63.8)	5 (11.4)			
Local anesthetic administration				0.908	0.303, 2.716	0.872
No	19 (25.7)	45 (60.8)	10 (13.5)			
Yes	8 (33.3)	13 (54.2)	3 (12.5)			
Explanation of benefits				1.277	0.425, 3.834	0.679
No	4 (25.7)	16 (60.8)	3 (13.5)			
Yes	23 (33.3)	42 (54.2)	10 (12.5)			
Duration of rubber dam placement				1.000	0.985, 1.016	0.179
Duration of rubber dam presence				0.978	0.961, 0.996	0.016*

*Significance level=0.05, OR: Odds ratio, CI: Confidence interval

and disagreement with previous research. Unlike previous research, this study showed a higher prevalence of neutral and negative attitudes, which contrasts with literature reviews and studies on Czech dental patients, which generally found more positive patient experiences.[8,9] This variation may be influenced by regional or demographic factors, or it could be attributed to the study's use of a more nuanced Likert's rating scale, which allowed for a more comprehensive assessment of attitudes compared with a simplified binary approach. Additionally, while using Bloom's cutting point could involve some loss of granularity and subjective interpretation, it allows for the analysis of more subtle associations and underlying trends.[11]

This study's ordinal regression analysis revealed a significant inverse relationship between the duration of rubber dam presence in the oral cavity and patient attitude scores, indicating that longer durations lead to less favorable patient attitudes. This aligns with the perception of 42.86% of participants who agreed that the duration of rubber dam presence was excessive. This finding is consistent with previous studies by Erin et al.[7] and Kapitan et al.,[8] which similarly identified perceived prolonged treatment time as a factor influencing attitudes. The mean duration of rubber dam presence in this study was 85±27.35 minutes, potentially influenced by treatment being provided by undergraduate students. According to Stewardson et al.,[12] patients treated by undergraduate students reported significantly fewer positive experiences with rubber dam compared to those treated by experienced dentists, where mean durations were notably shorter. The duration of treatment time approximately under 30 minutes for experienced dentists versus over 1 hour for undergraduates. This suggests that operator experience plays a role in patient perception, potentially by influencing the efficiency of rubber dam placement and overall treatment time.[13] Although the mean duration of rubber dam placement was longer in this study compared to some others, the duration of rubber dam placement itself was not a significant predictor of patient attitude.

In terms of agreement, this study aligns with previous research on several key points. The ordinal regression analysis revealed a significant inverse relationship between the duration of rubber dam presence and patient attitudes, confirming findings from studies that similarly identified prolonged treatment time as a negative factor. The study's finding that demographic factors such as gender and age showed no statistically significant influence on attitude scores is also consistent with some previous research.[7]

This study suggests that although patients generally hold a positive view of the clinical benefits of rubber dam, the practical experience of the procedure itself, particularly its duration, is a critical factor that influences their overall attitude. Patient attitude was significantly associated only with the duration of rubber dam presence. This finding aligns with the study's objective to identify the factors influencing patient attitudes and underscores the need for more efficient procedural skills for rubber dam application.

Furthermore, the high rates of patient agreement regarding the benefits of rubber dam and their preference for its future use corroborate the existing literature, indicating a strong patient understanding and acceptance of its protective advantages despite potential discomfort. Previous studies have indicated that factors influencing patient attitudes include comfort levels, explanations of rubber dam usage, and first-time experience. This study found that administering local anesthesia did not independently dictate overall rubber dam attitude.[14] In this study, the percentage of patients with prior rubber dam experience was notably higher than that in some other studies. The benefits of rubber dam in infection control, by decreasing microbial content in aerosols and droplets during treatment, particularly affect the patient's perception of rubber dam used in dental treatment during the COVID-19 pandemic context.

The lack of impact from the explanation for rubber dam usage in this study may be attributable to an invalid method used to convey its benefits or suboptimal communication skills among the dental students, differentiating their approach from that of experienced operators. This highlights the need for future research to validate assessment methods for evaluating patient comprehension of procedural benefits. A key finding was that patient discomfort, specifically issues with breathing, was the primary reason patients in the negative group rejected future rubber dam use. According to the association with the lowest mean score for negative statements, comfort and duration remain significant barriers to a positive experience Therefore, clinical training strategies should emphasize techniques to minimize airway obstruction (by ensuring the proper position of rubber dam sheet) and incorporating the atraumatic clamp technique, such as a cushee-rubber dam cushion (Praction Inc., USA) or customized cushee could be valuable for reducing postoperative pain and gingival trauma from clamp pressure.[15]

The use of rubber dam isolation in restorative dental treatment is clinically important in improving the longevity of restorations and ensuring safe procedures.[16] Minimizing the duration of rubber dam presence during treatment should be a primary consideration to enhance positive attitudes. Emphasizing effective communication strategies and application efficiency might help overcome practitioner-related barriers concerning patient acceptance, particularly for dental students.[8] Furthermore, longitudinal and qualitative research is required to determine whether the observed negative influence of prolonged procedural duration persists over time. Although this study focused on patients receiving operative treatment under rubber dam, exploring the attitudes of patients undergoing different procedures or in varied clinical settings could provide broader generalizability.

Limitations

The study's limitations owing to its single clinic setting and patient population, which consisted of individuals proficient in Thai. Additionally, the mean duration of the procedure was considerably longer than that associated with experienced dentists, which may influence the results. Although the sample size was statistically justified, it may not have been sufficient to detect smaller effects from other variables. Furthermore, reliance on a self-reported questionnaire is susceptible to various biases, such as recall bias or social desirability bias, despite efforts to mitigate them by having patients complete the form away from healthcare providers.

CONCLUSION

This study aimed to understand the factors associated with patient attitudes toward rubber dam use. Although the benefits of rubber dam are widely recognized by patients, procedural duration emerged as a key factor that significantly influenced patient attitude. This outcome indicates a clear need to enhance clinical training strategies focused on optimizing treatment time to improve patient satisfaction and acceptance of rubber dam use in operative treatment, thereby elevating the quality of patient care delivered by future health professionals.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was carried out with the permission of the Western University Human Researches Ethics Committee (Date: 26.12.2023, Decision No: HE-WTU2566-0112).

Informed Consent

All dentistry students signed an open and informed consent form.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

Data availability

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Review

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Conventional and digital approaches in post-endodontic restorations

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ABSTRACT

In endodontically treated teeth, the application of appropriate coronal restorations that restore functional and aesthetic integrity, prevent microbial ingress, and minimize the risk of fracture is essential for treatment success. The longevity of endodontically treated teeth in the oral cavity is influenced by multiple factors, including the amount of remaining tooth structure, the type of restorative material used, the restoration technique employed, and the interactions between the tooth, the restorative material, and the oral environment. Although various materials are available for the restoration of these teeth, composite resins and ceramics are among the most frequently preferred options in contemporary practice. Depending on the extent of coronal structure loss in posterior teeth, different therapeutic approaches can be employed, such as indirect composite resin restorations, indirect restorations (inlays, onlays, overlays), full crowns, and endocrowns.

Keywords: Endocrown, digital, 3D

INTRODUCTION

In the clinical success of endodontic treatment, the quality of the coronal restoration placed after therapy is of equal importance to the endodontic procedures performed during the treatment phase. Caries, trauma, previous restorations, and enlargement procedures conducted during endodontic preparation can result in substantial loss of coronal tooth structure in root canal–treated teeth. Following endodontic treatment, particularly in posterior teeth, it is essential to employ appropriate restorative treatments to minimize the risk of fracture, ensure coronal sealing to prevent bacterial contamination, and restore functional integrity. For this purpose, endodontically treated teeth can be restored through various methods, utilizing either direct or indirect restorative techniques.[1,2]

Among the conventional restorative approaches applicable after endodontic treatment are amalgam fillings, composite resin restorations, and fiber post applications. Advances in adhesive dentistry, the development of next-generation resin nanoceramic composite materials, the enhancement of strengthened ceramics, the capability to etch surfaces with acid, and the introduction of resin cements with high bonding strength have supported the concept that posterior teeth can be successfully restored without the use of post-core systems. Progress in adhesive systems has also enabled the pulp chamber to be utilized as a retention area, thereby allowing onlay and overlay restorations to be applied as alternatives to traditional treatment methods in the restoration of endodontically treated teeth with extensive coronal tissue loss. In line with these developments, the fabrication of monoblock crown restorations-known as endocrowns-which utilize the pulp chamber for retention, has become increasingly common, particularly in teeth with severe coronal destruction.[3,4]

In parallel with technological advancements, the rapid adoption of digitalization has become increasingly evident in the field of dentistry.[5] Intraoral and extraoral scanners have begun to replace conventional impression techniques, and CAD/CAM technologies now enable the digital design and fabrication of restorations. Compared to traditional impression methods, the ability to record intraoral and mandibular movements with greater precision allows for the fabrication of restorations that demonstrate superior adaptation and are more favorably accepted from an esthetic perspective. These advancements have the potential to reduce the necessity for restoration replacement due to treatment failure or misfit. Currently, while intraoral scanners are rapidly supplanting conventional impression methods, three-dimensional (3D) dental printing has emerged as an alternative manufacturing technology to CAD/CAM systems. Collectively, these digital tools and techniques offer patients a more comfortable clinical experience and provide clinicians with a more efficient workflow, along with a high potential for restorative success.[5-8]

RESTORATION OF ENDODONTICALLY TREATED TEETH

When selecting a restorative material, priority should be given to options that maximize the preservation of tooth

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structure, cause minimal removal of sound tissue, possess morphological and mechanical properties compatible with natural tooth structure, and demonstrate biocompatibility with oral tissues.[9] Endodontically treated teeth exhibit lower resistance to masticatory forces compared to vital teeth. The primary reasons for this include loss of tooth structure during the creation of the endodontic access cavity, reduced elasticity, and changes in cavity morphology. Various coronal restorative treatment options are employed to reestablish the functional integrity of the tooth, protect filled root canals against microleakage, and maintain occlusal stability. However, even when all treatment steps are performed correctly, the literature indicates that fracture rates in endodontically treated teeth are higher than those in vital teeth. Therefore, in cases with significant loss of tooth structure, the selection and application of an appropriate coronal restoration are of critical importance. In treatment planning, there is a direct relationship between the extent of existing structural loss and the type of coronal restoration to be selected.[10]

RESTORATIVE OPTIONS FOLLOWING ENDODONTIC TREATMENT

Traditionally, endodontically treated teeth have been restored using full crown restorations placed over post-core systems. However, during conventional treatment, the removal of sound tooth structure alters the biomechanical properties of the remaining dental tissues and weakens the tooth. In addition, the risk of root perforation and fracture associated with post placement has led to the investigation of alternative restorative approaches.[11-13] In parallel with the development of adhesive cements, the ease of use of fiber-reinforced composites, and the advancements in digital dentistry, various restorative options have recently been introduced as alternatives to conventional treatment methods.

Post-Core Restorations

Posts are utilized in cases where there is substantial loss of coronal tooth structure to ensure adequate retention of the core to the tooth. The primary functions of post placement include dissipating stress in structurally compromised teeth, preventing root fractures, providing a stable anchorage within the root canal, ensuring sufficient retention of the restoration, and supporting the coronal structure.[14] Currently, prefabricated metal posts, fiber posts, and ceramic posts are commonly used as post materials, while amalgam, composite resin, glass ionomer cement, and cast metal cores remain in clinical use as core materials.

Posts manufactured from metal, fiber, or ceramic differ from one another in terms of mechanical properties such as strength and elasticity. Metal and ceramic posts generally exhibit greater stiffness and higher strength compared to fiber posts, whereas fiber posts demonstrate greater elasticity, thereby exhibiting mechanical characteristics closer to that of dentin. Metal and ceramic posts are capable of withstanding functional forces, particularly lateral forces, without structural flexion; however, this rigidity may lead to concentration of stresses in the dentin, resulting in root cracks or fractures. In contrast, fiber post systems distribute occlusal forces more evenly, mimicking dentin-like behavior and thus reducing the potential risk of root fracture.[15,16] Esthetics is one of the essential considerations in post-core restorations. In cases where the final restoration is not planned as a metal-ceramic crown, the choice of post material can directly influence the esthetic outcome. Particularly in situations where esthetics is prioritized, ceramic posts and certain types of fiber posts may be preferred to achieve an appearance more closely resembling natural tooth structure.[17]

In restorations utilizing posts, various types of failures such as post deformation, loss of retention, root fracture, corrosion, and esthetic complications may occur. The primary cause of these failures is considered to be the excessive loss of tooth structure during endodontic treatment and post space preparation. Particularly in cases with narrow roots, the amount of remaining tooth structure after preparation for post placement may be insufficient, leading to an increased risk of fracture. Although several recommendations regarding post length exist, these guidelines are often modified in clinical practice according to the specific case. In the literature, post length has been described in various ways, which can be summarized in six approaches:

- The post length should be equal to the inciso-cervical or occluso-cervical height of the crown.
- The post should be longer than the crown height.
- The post length should be three-fourths (4/3) of the crown height.
- The post should be one-half, two-thirds (2/3), or four-fifths (4/5) of the root length.
- The post should terminate at the midpoint between the crestal bone level and the apex.
- The post should be of sufficient length to maintain apical seal integrity without compromising it.[18]

Fiber-Reinforced Direct Composite Restorations

Composite resin-based materials have been significantly improved in parallel with technological advancements. Due to their superior esthetic properties, strong bonding capability to dentin and enamel via adhesive systems, and ease of application under clinical conditions, they are widely preferred in modern dentistry. Although the most notable disadvantage of the material-polymerization shrinkage-has been considerably reduced in new-generation composites, its adverse effects on clinical success have not been completely eliminated.[19-21] Fiber meshes are employed to reduce polymerization shrinkage in composite resins, enhance the mechanical resistance of both the composite material and the remaining tooth structure, and improve fracture resistance. Owing to their high elastic modulus and low flexural modulus, they help to reduce stresses at the adhesive interface between the tooth and restorative material, thereby supporting the long-term success of the restoration. Following endodontic treatment, teeth that have lost their mesial and distal walls exhibit reduced resistance to occlusal forces. Over time, this may lead to fractures of the buccal or lingual walls, resulting in severe crown destruction that is often irreparable. To prevent such complications, the reinforcement of restorations in extensively damaged endodontically treated teeth with woven fibers has been proposed, and successful clinical outcomes using this technique have been reported in the literature.[22-24]

To enhance the mechanical resistance of coronal restorations, the placement position of woven fibers within the cavity can directly influence the success of the procedure. Oskoee et al.[25]

reported that positioning the woven fiber in the occlusal third to cover the buccal and palatal cusps resulted in a statistically significant increase in fracture resistance compared to placement in the middle third or gingival third. However, some studies have also reported that positioning the woven fiber solely in the gingival third can lead to an improvement in fracture resistance.[25,26]

Şengün et al.[27] investigated the effect of fiber mesh reinforcement on the fracture resistance of endodontically treated mandibular premolars with MOD cavity preparations. In the study, appropriate recesses were prepared in the buccal and lingual cusps to accommodate the placement of the fiber mesh, and these cusps were connected using the mesh. The findings revealed no statistically significant difference in fracture resistance between the specimens restored solely with composite resin and those reinforced with fiber mesh. However, when fracture patterns were evaluated, the group with fiber mesh reinforcement exhibited a higher incidence of restorable fractures compared to the non-reinforced group.

Recent advances in composite resin technology, including the development of novel monomers, improvements in translucency, initiator systems, and filler technology, have led to the introduction of bulk-fill composites. High-viscosity composite resins designed for bulk placement contain additional fillers aimed at enhancing the strength of the restored tooth. For example, alert (Jeneric/Pentron, Wallingford, Conn.) and everX Posterior (GC Corporation, Tokyo, Japan) composites incorporate glass fiber particles that provide specific mechanical advantages. These fiber-reinforced composites, designed for use as dentin replacement materials, have been reported to prevent the initiation of fractures and cracks in restorations and to inhibit the propagation of existing cracks. Therefore, in composite restorations with large cavity dimensions-particularly in endodontically treated teeth-the use of fiber-reinforced composites as a reinforcing base material, placed using the bulk-fill technique, is recommended.[28-30]

Indirect Composite Restorations

Currently, for teeth that have undergone significant structural loss following endodontic treatment, restoration with composite resin using an indirect technique is recommended. Indirect composite resin restorations are fabricated on a model obtained from an impression of the patient, either in a clinical or laboratory setting, and are polymerized under heat, light, and pressure in special furnaces. The fabricated restoration is then adapted intraorally and cemented with resin-based luting agents. The primary advantages of indirect composite resins over direct composite restorations include a reduction in polymerization stress within the material and an improvement in its physical properties. These enhancements in mechanical performance have been reported to increase the longevity of the restoration and reduce both occlusal and proximal wear. Compared to direct composite resin restorations, indirect composite restorations exhibit a more homogeneous and uniform microstructure.[4,31,32]

Inlay, Onlay, Overlay, and Full-Crown Restorations

Intracoronal restorations are classified as inlays, onlays, or overlays depending on the cavity design. Inlay restorations are indirect restorations applied to the occlusal, gingival, and proximal regions, and are considered more conservative compared to other restorative options. Although they do not mechanically reinforce the tooth, they aim to replace the lost tooth structure in a functional and esthetic manner. Inlays are generally preferred in premolar and molar teeth with limited carious involvement or pre-existing restorations. Onlay restorations, on the other hand, extend to cover the remaining portion of the occlusal surface, thereby distributing occlusal forces over a broader area and contributing to the protection of the tooth. Overlay restorations encompass not only the occlusal surface but also the buccal or lingual surfaces, providing a more comprehensive restorative solution. Common materials used for these restorations include metal, resin composite, all-ceramic materials, and polyetheretherketone (PEEK).[33]

In cases involving group guidance occlusion, pronounced occlusal anatomy, parafunctional habits such as bruxism or clenching, and advanced loss of tooth structure, restorative designs that encompass all cusps-such as onlays, overlays, endocrowns, or full crowns-should be considered. Additionally, in situations where the cavity size is extensive, the configuration factor of direct resin composites should be taken into account, and such indirect restorative options may be preferred. The selection of the indirect restoration type should be determined based on the amount and pattern of the remaining tooth structure. When the buccal and lingual walls are preserved at a height of 3-4 mm and a thickness of 1.5-2 mm from the floor of the pulp chamber, restorations covering all cusps can be performed without the need for post placement. In these restorations, stability is achieved through the macromechanical retention provided by the design and the micromechanical retention ensured by adhesive systems.[34]

Introduced into the dental literature in the 1980s, CAD/CAM technology has become increasingly prevalent in recent years in both dental clinics and laboratory settings. These systems enable faster, more reliable, and highly successful applications across various fields of dentistry. The primary advantages of CAD/CAM technology include the use of high-quality materials, reduced production costs, and the capability for patient-specific customization.[35]

In the application of indirect restorations, the carious tissues are first removed and the tooth is prepared. Impressions of the prepared tooth can be obtained using two different methods. The first method is the conventional impression technique performed with silicone-based impression materials. The second method involves taking digital impressions using CAD/CAM scanning systems. Based on the obtained impression, the restoration is fabricated either in a dental laboratory or in the milling unit of the digital scanning system. Once fabrication is complete, the restoration is adhesively cemented to the tooth using a specialized and precise resin-based luting cement.[36]

In cases where the coronal tooth structure has been significantly lost due to caries, restorative procedures, or endodontic treatment, full crowns can be applied as a restorative option. In certain cases, full crown restorations can be performed directly over the existing coronal structure. However, when adequate coronal support is not present, a post placed within the root canal must provide sufficient retention for both the core material and the crown restoration. Currently, metal-ceramic restorations and all-ceramic systems are among the preferred crown materials in clinical practice. Materials processable with CAD/CAM technology

range from feldspathic ceramics and leucite-reinforced glass ceramics, which have relatively low mechanical strength, to high-strength options such as lithium disilicate and zirconia. Furthermore, resin nanoceramics, zirconia-reinforced glass ceramics, and polymer-infiltrated ceramics have been increasingly utilized in recent years, offering alternative solutions in terms of both esthetics and mechanical performance.[33]

Endocrown Restorations

Endocrown restorations are monoblock (single-piece) restorations indicated for teeth with extensive loss of tooth structure, utilizing support from both the pulp chamber and the cavity margins. Macroretention is achieved through the pulpal walls, while microretention is provided by adhesive cementation. When evaluating the bonding surface, devital teeth present a larger surface area compared to vital teeth, raising the question of whether this could enhance the strength of the adhesive bond. Advances in adhesive technology, along with the reinforcement of contemporary ceramics, their ability to be etched, and their effective bonding to dental tissues with high-strength resin cements, have increased the applicability of endocrown restorations in the posterior region. However, in cases where the pulp chamber depth is less than 3 mm or the cervical margin width is less than 2 mm, endocrown restorations are contraindicated due to the inability to achieve sufficient bonding surface.[33,37]

The following parameters are recommended when performing endocrown preparations:

- The endodontic access cavity and the coronal pulp chamber should be prepared as a single continuous entity.
- Occlusal reduction should be achieved in the range of 2-3 mm.
- The preparation design should incorporate supragingival enamel margins whenever possible.
- Enamel should be preserved as much as possible to ensure strong adhesive bonding.
- A finish line with a width of 1-1.2 mm should be established at the restoration margin.
- The pulp chamber floor should be flattened using a suitable cavity base material.
- Internal cavity walls should be prepared with 90° butt joint margins.
- Axial walls should be prepared with a 6-10° taper to provide an appropriate path of insertion for the restoration.

All internal line angles should be rounded to reduce internal stress concentrations and enhance the adaptation of the restorative material.[38,39]

One of the primary advantages of endocrown restorations is that, when sufficient bonding surface is available, they do not require macroretentive preparation. Another significant benefit is the elimination of the need to prepare a post space within the root canal and construct a core structure. This approach not only reduces chair time but also minimizes the risk of root fractures that may occur as a consequence of post placement. Various modifications to the preparation can be made based on esthetic, biomechanical, and material-related requirements. These modifications may include reducing cuspal axial height to a lesser extent-particularly when using composite resin, applying the immediate dentin sealing technique to enhance bond strength, and incorporating either uniform or non-uniform ferrule designs into the preparation to maximize fracture resistance.[1,40,41]

Endocrown restorations can be fabricated either by pressing ceramic materials under pressure or by milling prefabricated ceramic blocks using CAD/CAM systems. In recent years, parallel to technological advancements, CAD/CAM systems have become increasingly favored for the fabrication of endocrowns. These systems eliminate multiple laboratory steps, thereby reducing potential errors during production, and allow the restoration to be delivered in a single clinical appointment. Additionally, they enable precise control over parameters such as layer thickness and cement space. Other notable advantages of CAD/CAM technology include the ability to achieve restorations with high marginal adaptation and the possibility of digital archiving. For these systems, endocrown restorations can be produced from a variety of specially developed block materials with distinct mechanical and esthetic properties.[4,42,43]

Composite resin blocks developed for CAD/CAM technology have been introduced as an alternative to ceramic blocks. Compared to ceramics, their relatively softer structure allows for faster milling and shaping processes. In addition, their repairability provides a significant clinical advantage. Hybrid ceramic materials such as Vita Enamic, which has a polymer-infiltrated ceramic network, and Cerasmart and Lava Ultimate, which possess a nanohybrid structure, have been introduced and incorporated into endocrown applications. One study reported that resin nanoceramic blocks exhibit higher fracture resistance compared to other CAD/CAM ceramics, such as feldspathic and lithium disilicate ceramics; however, due to their resin-based composition, they demonstrate higher microleakage values.[33,39,44]

Restorations Produced by Three-Dimensional (3D) Printers

Three-dimensional (3D) printing technology was first utilized in dentistry in 1999, when it was employed to fabricate an obturator to replace lost maxillary bone tissue. Over time, advancements in additive manufacturing techniques have enabled a wide range of treatment options within the field of dentistry. The primary advantages of 3D printers include reduced production time and costs, the ability to produce clean, safe, and rapid outputs, digital archiving capability, and the potential to fabricate restorations with minimal error, even in complex cases. Today, 3D printers used in dentistry can process a variety of materials, including polymers such as resin, polylactic acid (PLA), and thermoplastic elastomer (TPA), as well as glass, ceramics, zirconia, and metals such as titanium.[45]

The first-generation 3D printers predominantly employed the Fused Deposition Modeling (FDM) technique. However, due to its limitations such as insufficient resolution for fine details, porosity issues, and the inability of the fabricated materials to provide adequate mechanical strength for intraoral use this method is no longer preferred in current dental applications. Subsequently, selective laser sintering (SLS) technology, based on the principle of fusing metal powders using laser energy, was developed. This technique enables the fabrication of

implants, crown–bridge frameworks, and metallic bases for removable partial dentures.[5,46]

Since aesthetics, function, and hygiene are equally important in restorative dentistry, Digital Light Processing (DLP) and Stereolithography (SLA) printers capable of processing epoxy resin-based composite/ceramic hybrid materials have become more widely adopted than SLS systems in this field. In both techniques, the restoration is constructed layer by layer from a photopolymer resin; these layers are fused using an ultraviolet laser, and polymerization is achieved with ultraviolet light. The main advantage of SLA technology is its ability to produce large-volume restorations or models rapidly and at a low cost. DLP, on the other hand, stands out for its higher resolution and the optimization of materials to be more suitable for intraoral conditions. Today, the applications of 3D printing in restorative dentistry are diverse: FDM printers are generally used to fabricate whitening trays, dental retractors, and isolation devices, while DLP technology is employed for the production of inlay, onlay, veneer restorations, as well as temporary and permanent single crowns.[47,48]

CONCLUSION

In the restoration of endodontically treated teeth, the choice of restorative material, preparation technique, and applied technology directly influence the long-term clinical success. Current literature indicates that, when sufficient tooth structure remains, endocrown restorations offer an effective alternative to post–core systems and reduce the risk of root fracture. CAD/CAM-based fabrication techniques provide significant advantages in terms of precision fit and patient comfort. Nevertheless, the restorative approach in each clinical case should be individually planned, taking into account the amount of remaining tooth structure, occlusal loading conditions, and esthetic requirements.

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All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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Review

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Use of polyetheretherketone (PEEK) in prosthodontics

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ABSTRACT

Polyetheretherketone (PEEK) is a high-performance material that stands out among semi-crystalline thermoplastic polymers. Due to its chemical and physical durability, biocompatibility, and elastic modulus similar to that of human bone, it has become increasingly popular in dentistry. PEEK can be used in inlay, onlay, and endocrown restorations; as substructures for crowns and bridges; in removable denture frameworks; as an implant material; in implant-supported fixed or removable prostheses; and in the fabrication of occlusal splints. The aim of this review is to evaluate the current literature on the structure, properties, and use of PEEK material in prosthetic dentistry, which has recently become widely used, and to discuss its advantages and limitations compared to alternative materials.

Keywords: Polyetheretherketone, PEEK, dental prosthesis, polymers

INTRODUCTION

The primary objective of prosthetic dentistry is the functional and aesthetic rehabilitation of missing teeth, loss of tooth structure, and defects in the surrounding oral tissues through prosthetic restorations. Dental materials used for this purpose are required to exhibit biocompatibility, aesthetic properties similar to natural teeth, and sufficient mechanical strength under masticatory forces. To fulfill these requirements, metal-, ceramic-, and polymer-based materials are commonly utilized in prosthetic dentistry.[1]

Over the past three decades, advancements in computer-aided design and manufacturing (CAD/CAM) technologies have enabled the introduction of various forms of these material groups into clinical practice, significantly expanding the range of prosthetic material options. Consequently, clinicians have gained the ability to select the most appropriate material based on aesthetic and functional requirements.[1,2]

The inherent disadvantages of conventional metal and ceramic materials have paved the way for the introduction of high-performance polymers in the dental field. These polymers, characterized by a combination of high mechanical strength and low elastic modulus, stand out for their advantages such as rapid manufacturing, low cost, and biocompatibility. Among this group, polyetheretherketone (PEEK) was introduced into medicine in the late 1990s as a high-performance thermoplastic material in orthopedic and trauma treatments. Due to its chemical inertness, high wear resistance, adequate mechanical strength, low elastic modulus, and light weight, it has also become a significant alternative for dental applications.[3]

GENERAL PROPERTIES OF PEEK

PEEK is a semi-crystalline polymer belonging to the polyaryletherketone (PAEK) family, characterized by an aromatic and linear molecular structure composed of ketone and ether functional groups and aryl rings. Its melting temperature is 334°C, crystallization temperature is 343°C, and glass transition temperature is 145°C. Owing to its high thermal stability, it can be used at operating temperatures up to 260°C and maintains dimensional stability under temperature changes. Additionally, PEEK is a chemically inert material.[4,5]

Thanks to its excellent mechanical properties, biocompatibility, and high resistance to organic and inorganic chemicals, PEEK is an advantageous material for dental applications.[6] It is non-allergenic and non-toxic; with an elastic modulus of 3-4 GPa, it exhibits mechanical properties closer to bone compared to metal alloys and ceramics.[7] Its mechanical strength is unaffected by steam autoclaving, ethylene oxide, and gamma sterilization processes.[8] Its natural radiolucency ensures compatibility with imaging methods such as CT, MRI, and X-Ray.[9] Studies on PEEK have reported that it elicits a very low tissue response, has no adverse effects on cell cultures, does not harm osteoblasts or fibroblasts, and shows no cytotoxicity.[3]

PEEK offers significant advantages such as shock absorption, corrosion resistance, high wear and fracture resistance, excellent polishability, low plaque accumulation, and being lighter than metal restorations. Owing to its high resistance to friction and wear, it can also serve as a suitable framework material for precision attachment structures, such as bars and telescopic crowns.[10,11]

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Unfilled PEEK exhibits an elastic modulus of approximately 4 GPa and a tensile strength of around 100 MPa.[5] PEEK can be modified with structural additives to match the elastic modulus of cortical and cancellous bone density. Carbon fiber-reinforced PEEK (CFR-PEEK) can achieve tensile strength exceeding 200 MPa and an elastic modulus of approximately 20 GPa. The elastic modulus of carbon-reinforced PEEK, which is similar to that of cortical bone and dentin, contributes to reduced stress compared to titanium.[5,12] These mechanical properties help distribute stress transmitted to the bone more evenly, reducing the risk of bone resorption seen with more rigid materials like stainless steel and titanium. This makes PEEK a viable biomaterial alternative to titanium and stainless steel in medical and dental applications today.

In dentistry, PEEK has been employed as an implant material, implant abutment material, implant-supported digital impression post, implant-supported bar material, substructure material in implant-supported hybrid prostheses, healing cap material, substructure material in fixed prostheses, temporary crown material, major connector and clasp material in removable prostheses, and occlusal splint material.

USE OF PEEK IN REMOVABLE PARTIAL DENTURES

Removable partial dentures fabricated from cobalt-chromium (Co-Cr) material are an affordable and predictable treatment option for the rehabilitation of partially edentulous patients. However, due to the aesthetic limitations of metal clasps, increased prosthesis weight, metallic taste, and the risk of allergic reactions to metal alloys, thermoplastic materials such as polyamide and acetal resins have been developed for clinical use.[13] Polyamide materials reduce rotational forces transmitted to supporting teeth due to their low elastic modulus. However, their main disadvantages include the inability to reline the prosthesis and insufficient clasp retention compared to rigid prostheses. In contrast, acetal resins exhibit greater rigidity and mechanical durability than polyamide materials, yet they lack the natural translucency and vitality of conventional prosthetic materials.[13,14]

As an alternative to these materials, PEEK has increasingly been used as a framework material in removable partial dentures. A modified PEEK material (BioHPP; Bredent GmbH, Senden, Germany) with 20% ceramic fiber added, used in the fabrication of removable prostheses, is a high-performance polymer offering high biocompatibility, good mechanical properties, high thermal resistance, and chemical stability. It exhibits elasticity similar to bone and can reduce the stresses transmitted to the abutment teeth.[5,10,12] The white color of BioHPP frameworks provides an aesthetic alternative to conventional metal frameworks. Additionally, this material offers several advantages, including the prevention of allergic reactions and metallic taste formation, high polishability, low plaque affinity, and good wear resistance.

Despite all these advantages, Tannous et al.,[15] reported that clasps fabricated from PEEK material exhibit lower retention forces compared to Cobalt-Chrome (Co-Cr) clasps. However, PEEK clasps designed appropriately can provide sufficient retention at an undercut depth of 0.5 mm.

In PEEK frameworks, the stress caused by masticatory forces transmitted to periodontally weak teeth is lower compared to metal frameworks. However, it has been reported that the force transmitted to the mucosa is higher in PEEK frameworks in distal extension cases.[16] Chen et al.,[17] compared the stresses created by PEEK, titanium, and Co-Cr alloy frameworks on the mucosa in a distal extension case and noted that PEEK created more stress on the mucosa compared to other materials.

The weight of removable dentures can directly affect patient satisfaction. BioHPP enables the fabrications of lighter prostheses thanks to its low specific gravity, thereby increasing patient comfort and satisfaction. In a study, BioHPP-framed prostheses were reported to be 27.5% lighter than conventional Co-Cr framework partial dentures with a lingual bar design.[10]

The use of PEEK for reinforcing the base of complete dentures has been studied; however, it was reported that when designed with a thickness of 0.5 mm, it did not exhibit sufficient strength under the stresses encountered in the palatal region of the complete denture.[18]

USE OF PEEK IN FIXED PROSTHESES

Metal-free restorations are gaining increasing importance in dentistry due to patients' growing aesthetic expectations. PEEK is used as an alternative material in fixed prostheses due to its non-metallic color, low weight, and high strength.[19]

Its lighter weight compared with metal-ceramic restorations makes PEEK a suitable treatment option in cases where the weight of prosthetic restorations increases.[20] Low wear resistance, low solubility in oral fluids, an elastic modulus similar to dentin, and the ability to absorb masticatory forces highlight PEEK as an ideal material for fixed restorations. It is also an appropriate framework material for patients with metal allergies or sensitivity to metallic taste.[10]

Although it possesses optical properties closer to dental tissue compared to metals and metal alloys, it has been reported that the monolithic use of PEEK material is not suitable for restorations where aesthetics are important.[21] Due to its resistance to chemical agents, low surface energy, and resistance to surface modification processes, achieving strong bonding between PEEK and resin can be challenging. To achieve effective adhesion on the PEEK surface, mechanical and chemical pretreatments such as sandblasting, etching with a piranha solution (sulfuric acid and hydrogen peroxide mixture) or sulfuric acid (60-90 seconds), laser application, and plasma roughening are recommended. Following these processes, it is recommended to use an adhesive containing acetone, methyl methacrylate (MMA), or 10-metacryloyloxydecyl dihydrogen phosphate (MDP).[22] Due to PEEK's high resistance to chemical agents, etching with 9.5% hydrofluoric acid (HF), which is effective on glass-containing ceramics, is ineffective in altering the surface morphology of PEEK.[13]

Rocha et al.[23] evaluated the dentin bonding performance of PEEK using various surface treatments, including different application times of 98% sulfuric acid; sandblasting with 45 µm aluminum oxide particles; and sandblasting with 45 µm aluminum oxide particles followed by silica coating with 110 µm silicon oxide sand. Prolonged sulfuric acid application decreased bond strength, whereas sandblasting was found to be an effective method for modifying the PEEK surface.

For veneering PEEK frameworks, both light-cured composite resins and CAD/CAM-fabricated veneer layers can be

employed. It has been reported that PEEK restorations veneered using the CAD/CAM method exhibit a higher load-bearing capacity compared to those veneered with conventional composites. However, light-cured composites offer the advantage of allowing modifications to the restoration and the repair of minor fractures in the clinical setting.[24]

Stawarczyk et al.[25] reported that the fracture strength (1383 N) of a three-unit PEEK bridge fabricated using CAD/CAM was higher than that of lithium disilicate glass ceramic (950 N) and zirconia (981-1331 N). PEEK can be used in patients with bruxism.

USE OF PEEK IN IMPLANTS AND IMPLANT-SUPPORTED PROSTHESES

In implantology, PEEK is used as an implant material, and in the prosthetic phase, it serves as a healing cap, abutment, digital impression post, and restoration material.[26] Due to its biocompatibility and elastic modulus being very close to that of bone, PEEK has been proposed as an alternative to titanium as an implant material. However, its hydrophobic, bioinert nature and high contact angle reduce its osteoconductive effect and adversely affect osseointegration.[27] Therefore, to enhance the osteoconductive effect of PEEK, additional procedures such as laser surface modification, coating with bioactive materials, creating a wet chemical surface, and incorporating bioactive components such as hydroxyapatite and titanium dioxide into the PEEK matrix have been recommended.

In a finite element analysis, Lee et al.[28] reported that carbon fiber-reinforced PEEK implants may result in lower force transmission compared to titanium implants. Conversely, another finite element analysis suggested that there is no difference between PEEK and titanium implants in terms of stress distribution.[29] PEEK implants are not widely used, and there is insufficient data to evaluate their long-term efficacy in human subjects.

Custom healing abutments can be fabricated from PEEK material to achieve an optimal emergence profile around the implant. Due to its lower fracture resistance compared to zirconia and titanium, PEEK is generally used as a temporary abutment material.[30] In a randomized controlled clinical trial, Koutouzis et al.[31] reported no significant differences between PEEK and titanium abutments in terms of soft tissue inflammation and bone resorption.

One of the most common complications associated with implant-supported overdenture attachments is the loss of retention due to wear over time. To improve the retention of the prosthesis by increasing bite force and wear resistance, retentive caps and clips made from PEEK have been developed. With a flexural strength of approximately 140-170 MPa, PEEK exhibits a stress-breaking effect by absorbing functional stresses.[32]

In a study comparing different clip types used in Locator attachments, PEEK and nylon materials were evaluated. PEEK clips demonstrated higher bite force and lower wear rates throughout all evaluation periods, leading to the conclusion that they could serve as an alternative to nylon clips.[33]

USE OF PEEK IN OBTURATORS

Maxillary obturator prostheses are typically made from polymethyl methacrylate (PMMA) in completely edentulous patients and from a combination of a cast metal framework and PMMA in partially edentulous patients. As the surgical resection area increases, the area covered by the prosthesis and, consequently, its weight also increases. PEEK offers advantages in obturator prostheses due to its high biocompatibility and light weight. Digital design and fabrication of PEEK obturators can be performed using computed tomography images.[2,15] Costa Palau et al.[34] reported in their clinical study that the PEEK obturator prosthesis fabricated using the CAD/CAM system for a patient with an oronasal defect was superior to conventional obturators in terms of function, retention, and aesthetics, and was also lighter.

USE OF PEEK IN OCCLUSAL SPLINTS

Occlusal splints are commonly used appliances for the diagnosis and management of temporomandibular joint (TMJ) disorders and are traditionally fabricated from acrylic resin. Traditionally, occlusal splints fabricated from acrylic resin have disadvantages such as an unpleasant taste, dimensional changes, residual monomer release, color changes, and susceptibility to fracture, which create difficulties for patients in terms of use. PEEK is used as an alternative material in the fabrication of occlusal splints due to its high wear resistance, lightweight nature, and ability to absorb shock under severe occlusal forces.[35]

In a study comparing the surface roughness and wear resistance of occlusal splint materials, PEEK was found to yield better results than other materials.[36] Wang et al.[37] compared the preclinical effects of digital occlusal splints with conventional hard splints in patients with sleep bruxism and reported that PEEK occlusal splints showed less wear after 12 weeks of follow-up and possessed properties capable of meeting clinical requirements. Furthermore, owing to their physical properties, PEEK splints can be fabricated in thinner forms, thereby increasing patient satisfaction.

CONCLUSION

PEEK has emerged as a significant alternative material in prosthetic dentistry owing to its high mechanical strength, biocompatibility, low specific weight, bone-compatible elastic modulus, and chemical stability. Its applications range from fixed, removable, and implant-supported prostheses to occlusal splints and maxillofacial prostheses. Nevertheless, it presents certain limitations, including aesthetic constraints, challenges in adhesive bonding due to surface characteristics, and variations in mechanical performance in specific clinical situations. While current literature supports the short- and medium-term clinical success of PEEK, further studies are required to evaluate its long-term clinical outcomes and performance across various prosthetic indications.

ETHICAL DECLARATIONS

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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