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Journal of Dental Sciences and Education

Original Article

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Hierarchy of research study designs: a conceptual and illustrative approach for scientific education

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ABSTRACT

Aims: To present an educational conceptual framework for understanding research study designs, emphasizing their methodological relationships and educational value as tools to support scientific literacy and methodological understanding.

Methods: This conceptual and educational article was developed based on classical references in scientific methodology, evidence-based practice, and cognitive learning theories. International reporting guidelines and methodological frameworks, including CONSORT, STROBE, PRISMA, the Cochrane Handbook, and GRADE, were considered in the theoretical organization of the proposed models. Two visual representations were developed to illustrate the relationships among descriptive, observational, and interventional designs, as well as the distinction between primary and secondary studies. The figures were refined by consensus among the authors, prioritizing conceptual coherence and pedagogical applicability.

Results: The proposed visual models provide an integrated perspective on research study designs, highlighting their methodological characteristics, inferential potential, and complementary roles in knowledge production. Rather than reinforcing rigid hierarchical classifications, the models emphasize functional and conceptual relationships among different study designs. By promoting cognitive organization and reducing the complexity associated with abstract methodological concepts, these representations may facilitate critical reading and improve methodological understanding among students and novice researchers.

Conclusion: The proposed conceptual models complement traditional evidence pyramids by emphasizing methodological relationships rather than evidence hierarchy. As educational frameworks grounded in cognitive learning principles, they may facilitate the teaching of research methodology, strengthen methodological reasoning, and promote a more integrated understanding of evidence generation in dentistry and other health professions.

Keywords: Higher education, scientific methodology, evidence-based practice, decision-making, knowledge

INTRODUCTION

Scientific training in health sciences requires students not only to master technical and clinical competencies but also to develop the ability to critically understand, interpret, and apply knowledge generated by the scientific literature.[1,2] The exponential growth of academic publications over recent decades has transformed the information landscape into an increasingly complex environment,[3] in which multiple study designs coexist, each addressing distinct research questions and operating under different methodological assumptions.[4]

Within this context, research study designs play a central role in the generation of scientific knowledge,[5-7] as they provide the framework for the observational, comparative, analytical, and inferential strategies adopted by researchers.[2,3] A sound understanding of these methodological approaches is particularly important during academic training, as conceptual difficulties frequently observed among students may compromise both the critical appraisal of the literature and the development of scientific investigations.[8-10]

Evidence-based practice has emerged as one of the most influential paradigms in contemporary health sciences, advocating the integration of the best available scientific evidence with professional expertise and contextual factors relevant to decision-making.[10,11] Within this framework, different study designs have traditionally been organized into hierarchical structures,[12] such as evidence pyramids, which graphically represent relationships among methodological rigor, control of bias, and the potential for causal inference.[4-6,13]

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Although widely disseminated, these hierarchical representations have been the subject of considerable debate within the methodological literature. Classical studies have emphasized that scientific validity and relevance depend not exclusively on study design,[14] but also on the quality of study conduct, analysis, and interpretation.[10-13] Moreover, rigid hierarchical interpretations may promote reductionist views, obscuring the complementary nature of different research methodologies.[15,16]

Conceptual difficulties related to distinguishing observational from experimental studies, cross-sectional from longitudinal designs, and primary from secondary studies are frequently reported in health professions education.[1,10-12,16] These challenges highlight the need for pedagogical approaches capable of promoting conceptual clarity, cognitive organization, and an integrated understanding of methodological strategies.[17,18]

From an educational perspective, cognitive theories of learning suggest that visual representations can play an important role in the assimilation of abstract concepts and the organization of knowledge.[14-18] Well-structured graphical models may reduce cognitive load, facilitate the construction of conceptual schemas, and enhance understanding of the relationships among different study categories.[19]

Furthermore, the availability of educational resources in Portuguese deserves particular attention. Although most methodological literature is published in English, language barriers remain a significant challenge for students in training.[1] The development of educational materials in Portuguese may therefore broaden access to knowledge and contribute to strengthening scientific literacy.[20]

Despite the widespread use of evidence pyramids and other hierarchical representations of research study designs, there remains a gap in the development of visual models that integrate the methodological foundations of scientific research with cognitive principles of learning. This gap is especially relevant in health professions education, where students often experience difficulties in understanding the relationships among different study designs and their epistemological implications. Consequently, there is a need for approaches that move beyond rigid classifications and foster a more integrated, critical, and pedagogically oriented understanding of research methodologies.

Although several evidence pyramids and graphical classifications of research designs have been published, most were developed primarily to represent levels of evidence or methodological rigor. In contrast, the present proposal does not seek to establish a new hierarchy or replace existing frameworks. Instead, it introduces an educational model designed to integrate methodological concepts with cognitive learning principles, emphasizing the functional relationships among research designs and their complementary roles in answering different scientific questions. This pedagogical perspective represents the principal innovative aspect of the present work. Unlike conventional evidence pyramids, which primarily aim to classify research designs according to methodological hierarchy, the present models were intentionally conceived as conceptual educational frameworks. Their purpose is not to redefine levels of evidence but to facilitate conceptual understanding by explicitly illustrating the relationships among study designs and their complementary roles in scientific knowledge generation. The simplicity of the graphical organization was intentionally preserved to promote conceptual clarity and reduce unnecessary cognitive load, allowing learners to focus on methodological reasoning rather than on visual complexity.

In dental education, the ability to critically interpret scientific evidence has become increasingly important owing to the growing emphasis on evidence-based dentistry and lifelong learning. Dental professionals are continuously exposed to an expanding body of scientific literature addressing preventive, diagnostic, restorative, orthodontic, periodontal, and surgical interventions. Consequently, understanding the strengths and limitations of different research designs is essential for critically appraising evidence and translating research findings into clinical decision-making. Educational tools capable of facilitating this understanding may therefore contribute directly to improving evidence-based dental practice.

Accordingly, the present article proposes a conceptual and illustrative approach to the hierarchy of research study designs in health sciences. The aim is to present visual models conceived as educational tools to assist students and early-career researchers in understanding the methodological and epistemological relationships among different scientific study designs.

METHODS

Ethics

No ethics committee approval was required for this study because no human participants, patient data, photographs, or biological materials were involved. The investigation was conducted entirely using information retrieved from the literature. Therefore, according to institutional and international guidelines, ethical approval and informed consent were not necessary.

Conceptual Development and Construction of Visual Models

This study constitutes a conceptual article with an educational purpose, grounded in established theoretical frameworks from scientific methodology, evidence-based practice, and cognitive learning theories.[1-6,14-18] The development of the proposed framework was informed by classical references in health research methodology, international reporting guidelines, and epistemological perspectives on scientific knowledge generation.

The conceptual foundation of the study was based on three complementary domains: (1) methodological principles underlying research study designs and scientific inference,[5-9,21,22] (2) mechanisms of bias control and evidence appraisal in clinical and observational research,[10-13,23] and (3) cognitive theories emphasizing the role of visual representations in facilitating conceptual learning and knowledge organization.[14-18]

Widely adopted frameworks for the generation, reporting, and synthesis of scientific evidence, including CONSORT, STROBE, PRISMA, the Cochrane Handbook, and GRADE, were considered in the theoretical organization of the proposed models.[5-9] These references provided the methodological basis for distinguishing between descriptive,

observational, experimental, primary, and secondary study designs. No predefined graphical framework or previously published visual model was adopted during the design process. Instead, the proposed figures were developed as original conceptual representations intended to synthesize established methodological knowledge into an educational resource capable of facilitating conceptual understanding among students and novice researchers.

The development of the visual models followed an iterative three-stage process. Initially, the principal categories of research study designs were identified and organized according to classical methodological literature, evidence-based practice frameworks, and international reporting guidelines. Subsequently, preliminary conceptual diagrams were independently drafted to represent the methodological relationships among study designs, considering their investigative purpose, degree of bias control, inferential potential, and educational applicability. Rather than adapting an existing graphical template or previously published evidence pyramid, the figures were conceived as original educational models integrating methodological concepts with principles derived from cognitive learning theory. Finally, successive versions of the diagrams were critically reviewed by all authors through iterative discussions until consensus was achieved regarding conceptual organization, methodological accuracy, educational relevance, visual clarity, and internal consistency.

The figures presented were conceived exclusively as pedagogical tools. **Figure 1** was designed to illustrate the methodological relationships among descriptive, observational, and interventional studies, highlighting their distinct analytical approaches and investigative strategies. **Figure 2** represents an adapted conceptual pyramid aimed at clarifying the distinction between primary and secondary studies and their respective roles in knowledge generation and evidence synthesis. Unlike conventional evidence pyramids, the proposed models were intentionally designed to emphasize conceptual organization rather than hierarchical ranking, integrating methodological relationships with educational principles derived from cognitive learning theories.

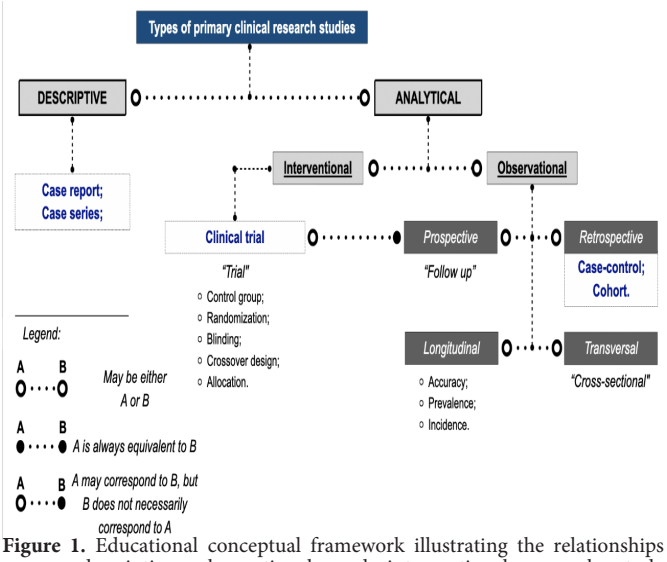

Figure 1. Educational conceptual framework illustrating the relationships among descriptive, observational, and interventional research study designs. The figure emphasizes the complementary methodological roles of each design and was intentionally developed as a simplified conceptual representation to facilitate learning and methodological understanding rather than to establish a hierarchy of evidence

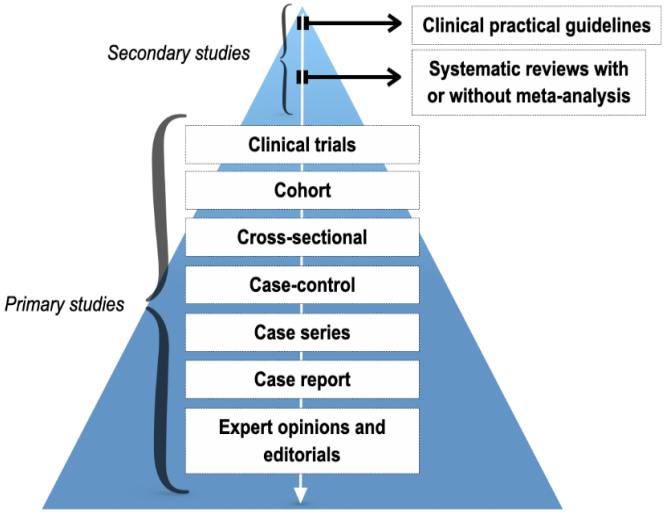

Figure 2. Educational conceptual framework illustrating the distinction between primary and secondary research. The figure emphasizes the complementary processes involved in evidence generation and synthesis and was intentionally designed to support conceptual understanding in research methodology education

RESULTS

Development of Conceptual Frameworks for Understanding Research Study Designs

The principal outcome of this conceptual study was the development of an educational framework composed of two complementary visual models and a structured summary table designed to facilitate the teaching and learning of research methodology. Together, these educational resources aim to improve conceptual organization, strengthen methodological reasoning, support critical appraisal of scientific literature, and promote scientific literacy among undergraduate students, graduate trainees, and early-career researchers. Rather than functioning as simple graphical representations, the proposed models were conceived as pedagogical tools to facilitate meaningful learning and evidence-based decision-making.

Two complementary visual models were developed to support the teaching and understanding of research study designs in health sciences. The originality of these models resides in their emphasis on conceptual integration rather than evidence ranking. By illustrating the relationships among study designs according to their methodological characteristics and investigative purposes, the framework encourages students to understand research designs as complementary methodological strategies instead of isolated hierarchical categories.

The first model (**Figure 1**) provides a conceptual representation of the relationships among descriptive, observational, and interventional study designs. Rather than emphasizing hierarchical rankings, the framework highlights methodological characteristics, investigative strategies, and the distinct roles played by each design in addressing specific research questions. This approach underscores the complementary nature of different methodological traditions and their contributions to scientific knowledge production.

The second model (**Figure 2**) presents an adapted conceptual pyramid intended to facilitate the differentiation between primary and secondary studies. The framework illustrates the progressive integration and synthesis of evidence while

emphasizing that the strength and applicability of scientific findings depend not only on study design but also on methodological quality and context of application.

The visual frameworks were developed to promote conceptual clarity and cognitive organization. By integrating methodological principles with educational theories of learning, the models aim to reduce the complexity associated with abstract concepts and provide a more relational understanding of research designs. In contrast to traditional hierarchical representations, the proposed models emphasize the interconnected and complementary roles of different forms of scientific evidence. The proposed models were intentionally designed using a simplified graphical structure to facilitate cognitive processing and avoid unnecessary visual overload. Rather than incorporating multiple visual elements, the educational emphasis lies in promoting conceptual organization and helping learners understand how different study designs relate to one another according to their methodological purpose.

In addition to the proposed visual models, **Table** presents a structured summary of the principal research study designs, highlighting their methodological characteristics, strengths, limitations, and educational relevance. Collectively, these educational resources provide an integrated framework that allows learners to distinguish research designs according to their methodological purpose rather than solely their position within traditional evidence hierarchies. This approach encourages deeper conceptual understanding and may facilitate the transfer of methodological knowledge to evidence-based clinical decision-making, particularly in dental education. Rather than emphasizing a rigid hierarchy, the table underscores the complementary roles of different study designs in answering specific research questions and generating scientific evidence. By integrating methodological and pedagogical perspectives, this resource aims to support the development of scientific literacy, critical appraisal competencies, and evidence-based decision-making skills. The table was conceived as an educational tool intended to facilitate meaningful learning and to provide students and novice researchers with a comprehensive framework for understanding the diverse approaches used in health research.

From an educational perspective, the frameworks were designed to support scientific literacy and critical appraisal skills among undergraduate students, graduate trainees, and early-career researchers. Their pedagogical purpose is to facilitate meaningful learning by providing a structured and visually accessible representation of the relationships among research methodologies. The proposed framework may be incorporated into dental research methodology courses, evidence-based dentistry modules, journal clubs, and scientific initiation programs, providing a practical educational resource to facilitate the interpretation of research evidence. In undergraduate education, the models may be used during introductory courses in research methodology and evidence-based dentistry to assist students in distinguishing among descriptive, observational, and experimental research designs. In postgraduate education, they may support journal clubs, critical appraisal activities, and discussions on research planning. At the doctoral level, the framework may facilitate advanced seminars on scientific methodology, evidence synthesis, and the selection of appropriate study designs for complex research questions.

Overall, the proposed educational framework represents a practical teaching resource that may support undergraduate and postgraduate curricula, journal clubs, scientific initiation programs, and evidence-based dentistry courses by improving students' understanding of research methodology and fostering more critical interpretation of scientific evidence.

DISCUSSION

The hierarchical organization of research study designs emerged historically as a pedagogical framework closely associated with evidence-based practice, aiming to guide the appraisal and interpretation of scientific literature.[2-6] Traditional evidence pyramids were developed to represent gradients of methodological rigor and inferential strength, thereby contributing to the systematization of scientific reasoning and evidence synthesis.[24] Nevertheless, methodological literature has consistently emphasized that these hierarchies should not be interpreted in a rigid or deterministic manner because the validity and applicability of scientific evidence depend not only on study design but also on methodological quality, risk of bias, statistical analysis, and the clinical context in which the findings are applied.[10-13]

From an epistemological perspective, scientific knowledge is generated through complementary methodological approaches rather than through a strictly linear progression of evidence.[19-22] Descriptive, observational, experimental, and evidence synthesis studies address distinct scientific questions and collectively contribute to a comprehensive understanding of health phenomena.[25] Consequently, educational strategies that encourage learners to recognize these complementary relationships may provide a more meaningful understanding of research methodology than approaches focused exclusively on evidence hierarchy.

The principal contribution of the present study is therefore educational rather than classificatory. Unlike conventional evidence pyramids, which primarily organize study designs according to levels of evidence, the proposed framework was intentionally developed to facilitate conceptual understanding by illustrating the methodological relationships among research designs. Rather than proposing a new hierarchy, these models encourage learners to understand why different

Table. Characteristics of major research study designs and their educational implications

Design	Category	Main purpose	Strengths	Limitations	Educational relevance
Cross-sectional	Observational	Prevalence	Simple	No causality	Understanding associations
Case-control	Observational	Risk factors	Efficient	Recall bias	Critical appraisal
Cohort	Observational	Incidence	Temporal sequence	Cost	Longitudinal thinking
RCT	Experimental	Causality	High internal validity	Expensive	Gold standard concept
Systematic review	Secondary	Evidence synthesis	Comprehensive	Quality-dependent	Evidence-based dentistry

RCT: Randomized controlled trial

study designs are appropriate for different research questions and how they collectively contribute to evidence generation. This conceptual perspective aligns with contemporary educational approaches that emphasize understanding relationships among concepts instead of memorizing isolated classifications.

Recent evidence in health professions education further reinforces the value of structured visual educational resources. A recent systematic review demonstrated that Visual Thinking Strategies enhance observation, analytical reasoning, communication, and reflective thinking among healthcare students, supporting the educational use of conceptual visual frameworks beyond their illustrative function.[26] Likewise, systematic reviews have shown that visual educational resources, including animations and other multimedia tools, improve learner engagement, knowledge acquisition, and retention when integrated into pedagogically structured activities rather than presented as passive instructional materials.[27] These findings support the rationale for developing simplified conceptual models capable of facilitating methodological reasoning during research training.

The intentionally simplified graphical organization adopted in the present framework is also consistent with cognitive theories of learning. Cognitive load theory and multimedia learning theory propose that reducing unnecessary visual complexity allows learners to allocate greater cognitive resources to essential conceptual processing.[14,15] Rather than incorporating multiple visual elements, colors, or directional arrows, the present models were intentionally designed to preserve conceptual clarity and reduce extraneous cognitive load. Their educational value therefore resides primarily in the explicit representation of methodological relationships rather than in graphical complexity.

The proposed framework may be incorporated into different educational settings throughout the continuum of dental education. During undergraduate training, the models may support introductory courses in research methodology and evidence-based dentistry by helping students distinguish descriptive, observational, and experimental study designs before critically appraising scientific articles. In postgraduate education, they may facilitate journal clubs, evidence-based dentistry courses, and research proposal development by encouraging methodological reasoning and study design selection. At the doctoral level, the framework may serve as a conceptual resource for advanced discussions on evidence synthesis, methodological decision-making, and research planning. These educational applications are consistent with learner-centered strategies such as flipped classrooms, collaborative discussions, and case-based learning, which have demonstrated positive educational outcomes in health sciences education.[28]

The increasing incorporation of digital educational technologies into health professions education further strengthens the relevance of concise conceptual learning resources. Recent analyses of digital teaching demonstrate that interactive visual materials have become increasingly important components of contemporary medical education, complementing traditional face-to-face instruction and supporting hybrid learning environments.[29] In this context, the proposed models represent a low-cost, easily reproducible educational resource that can be incorporated into classroom teaching, online learning platforms, journal clubs, scientific initiation programs, and continuing professional education.

Limitations

Some limitations of the present study should be acknowledged. Because this work represents a conceptual educational proposal, the visual models have not yet been empirically validated in formal educational settings. Furthermore, the interpretation of methodological relationships may vary according to disciplinary context and research objectives. Future investigations should evaluate the educational effectiveness of these conceptual models using objective educational outcomes, including knowledge acquisition, long-term retention, methodological reasoning, critical appraisal performance, and learner satisfaction. Comparative studies evaluating the proposed framework against traditional evidence pyramids may further clarify its educational value.

In summary, the present study proposes an educational framework that complements, rather than replaces, conventional evidence pyramids. By integrating methodological concepts with principles derived from cognitive learning theories and contemporary health professions education, the proposed models encourage a more relational understanding of research study designs. This approach has the potential to strengthen methodological reasoning, support evidence-based dentistry education, and promote meaningful learning among undergraduate, postgraduate, and early-career researchers.

CONCLUSION

The conceptual models proposed in this study complement existing evidence pyramids by shifting the educational focus from evidence hierarchy to the understanding of methodological relationships among research study designs. Grounded in cognitive learning principles, they provide an original educational framework designed to facilitate methodological reasoning, conceptual organization, and evidence-based learning through clear and simplified visual representations. Their potential application across undergraduate, postgraduate, and doctoral education, including research methodology courses, evidence-based dentistry, journal clubs, and scientific training, highlights their relevance as practical teaching resources for dental education. Although further educational validation is warranted, these models offer a novel pedagogical contribution that may promote meaningful learning and foster a more critical, integrated, and clinically relevant understanding of evidence generation in dentistry and other health professions.

ETHICAL DECLARATIONS

Ethics Committee Approval

No ethics committee approval was required for this study because no human participants, patient data, photographs, or biological materials were involved.

Informed Consent

As no biological material from humans or animals was used in the study, informed consent was not required.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

Financial Disclosure

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Author Contributions

Concept: LSCB, ICS, CCAQ, LMDM; Design: LSCB, ICS, LMDM; Control: CCAQ, LMDM; Data Collection and/or Processing: LSCB, ICS, ROS; Analysis and/or Interpretation: LSCB, ICS, ROS, LMDM; Writing the Article: LSCB, ROS, LMDM; Critical Review: LSCB, ROS, CCAQ, LMDM.

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Original Article

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Virtual reality and haptic simulation in preclinical dental education: a bibliometric analysis

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ABSTRACT

Aims: This study aimed to provide a bibliometric overview of research on virtual reality (VR) and haptic simulation in preclinical dental education, focusing on publication trends, research themes, international collaboration, and applications across dental disciplines.

Methods: Scopus was searched on July 13, 2026, for English-language original research articles involving dental students, VR or haptic simulation, and educational outcomes. Of 555 identified records, 176 met the eligibility criteria. Bibliometric indicators were analyzed using Microsoft Excel, and keyword co-occurrence, country-level co-authorship, and bibliographic coupling analyses were performed using VOSviewer.

Results: The 176 publications, published between 2003 and 2026, received 3.818 citations. More than half (54.5%) were published between 2024 and 2026, with the highest annual output in 2025. The Journal of Dental Education was the most productive journal. China had the highest publication output, whereas the United Kingdom had the highest total link strength in the country-level collaboration network. Keyword analysis showed a shift from skill acquisition and computer-assisted instruction toward more recent themes including preclinical training, virtual simulation, and haptic simulation. Restorative and operative dentistry was the most represented discipline (36.4%), followed by endodontics (15.9%) and oral surgery/implantology (15.3%).

Conclusion: Research on VR and haptic simulation in preclinical dental education has expanded considerably in recent years. The findings reveal evolving research themes, differences in international collaboration, and a concentration of research in disciplines requiring procedural and psychomotor skills. This overview may help identify less explored areas and guide future research in technology-supported dental education.

Keywords: Bibliometrics, dental education, simulation training, virtual reality, dental students

INTRODUCTION

Dental education requires students to develop a combination of theoretical knowledge, clinical reasoning, and fine psychomotor skills before providing patient care. This is particularly important during preclinical training, where students are expected to acquire manual skills and procedural competence within a controlled learning environment. Conventional simulation methods using phantom heads and typodont teeth have long formed the basis of this training. However, advances in digital technologies have introduced new educational approaches that can complement traditional methods and provide students with more interactive and standardized learning experiences.[1,2]

Among these technologies, virtual reality (VR) and haptic simulation have gained increasing attention in dental education. VR-based environments can simulate clinical or preclinical procedures, while haptic systems add tactile and force feedback that more closely reproduces the sensory experience associated with manipulating dental tissues and instruments.[3,4] These systems allow students to repeat procedures in a controlled environment and may provide objective and immediate feedback on aspects of their performance. Their applications have consequently expanded beyond individual procedures to several areas of dental education, including restorative and operative dentistry, endodontics, prosthodontics, oral and maxillofacial surgery, and pediatric dentistry.[5,6]

The growing interest in digital educational technologies is also reflected in the dental education literature. Recent bibliometric studies have identified virtual reality and educational technology among emerging areas of interest, suggesting an increasing shift toward digitally supported learning environments.[7,8] Bibliometric analysis provides a quantitative approach for examining such developments by evaluating publication trends, citation patterns, research themes, and collaboration networks. It can therefore provide a broader perspective on how a research field has developed, identify influential contributions, and reveal emerging areas of scientific interest.[9-11]

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Previous bibliometric studies have examined specific aspects of immersive and simulation-based technologies in dental education. Hsu and Chang[2] evaluated research on haptic and force-feedback technologies published between 2001 and 2022, whereas a more recent scientometric study focused specifically on global haptic simulation research between 2020 and 2025.[2,12] Another bibliometric analysis examined VR applications specifically within restorative dentistry.[3] Although these studies provide useful insights into particular technologies, periods, or dental disciplines, a broader bibliometric evaluation focusing specifically on the use of both VR and haptic simulation for preclinical dental education and skill development across dental disciplines remains limited.

Therefore, the present study aimed to provide a comprehensive bibliometric analysis of research on virtual reality and haptic simulation in preclinical dental education. Specifically, the study evaluated publication trends, leading journals and countries, citation patterns, international collaboration, keyword networks, bibliographic relationships, and the distribution of applications across dental disciplines. By mapping the development and current structure of this research field, the findings are intended to provide an overview of existing research patterns and identify areas that may guide future studies in technology-supported preclinical dental education.

METHODS

Ethics

This study was based exclusively on publicly available bibliographic data retrieved from the Scopus database and did not involve human participants, animals, identifiable personal data, or biological materials. Therefore, ethics committee approval and informed consent were not required. Scopus was selected as the data source because of its broad coverage of peer-reviewed literature and the availability of bibliographic and citation information suitable for bibliometric analysis. All procedures were carried out in accordance with the ethical rules and the principles.

Database and Search Strategy

The literature search was conducted on July 13, 2026 using the title, abstract, and keyword fields (TITLE-ABS-KEY) with the following search strategy:

TITLE-ABS-KEY [("virtual reality" OR "virtual simulation" OR "haptic" OR "haptic simulation" OR "haptic feedback") AND ("dental education" OR "preclinical dental education" OR "preclinical training" OR "dental student*")]

The initial search identified 555 records. After restricting the results to articles published in English, 392 records remained for screening. No subject-area restriction was applied because relevant studies on dental education may be published in multidisciplinary or medical education journals and could therefore be missed by limiting the search to the Dentistry subject area.

Eligibility Criteria and Study Selection

Original research articles were eligible if they investigated virtual reality or haptic simulation as an educational or training intervention involving dental students, addressed preclinical education or skills training, and evaluated at least one educational outcome. Studies focusing on student performance, skill acquisition, procedural accuracy, learning effectiveness, or other training-related outcomes were considered within the scope of the analysis.

Reviews, bibliometric studies, editorials, opinion papers, and other non-original publications were excluded. Studies focusing on VR applications for patient treatment, patient management, or anxiety reduction were also excluded, as were technical development studies without educational evaluation involving dental students and publications unrelated to dental education.

The titles and abstracts of the 392 records were manually screened according to these predefined criteria. When eligibility could not be determined from the available information, the record was examined in greater detail. Following screening, 176 publications met the eligibility criteria and were included in the final bibliometric analysis.

Data Extraction and Bibliometric Analysis

Bibliographic data for the included publications were exported from Scopus in CSV format. The extracted information included authors, titles, publication years, source titles, affiliations, citation counts, keywords, and cited references. Microsoft Excel was used to organize the data and analyze annual publication output, citation patterns, leading journals, contributing countries, and highly cited publications.

Network analyses and scientific mapping were performed using VOSviewer (version 1.6.21). The analyses included keyword co-occurrence analysis, country-level co-authorship analysis, and document-level bibliographic coupling. Default counting methods were used for the respective analyses, with full counting applied where available.

For keyword co-occurrence analysis, author keywords occurring at least five times were included, and a thesaurus file was used to merge synonymous or closely related terms. For example, "VR" was merged with "virtual reality", "haptic simulator" and "haptic technology" were merged under "haptic simulation", and singular and plural forms (e.g., "dental student" and "dental students") were unified before analysis. Country-level co-authorship analysis included countries with at least five publications. Bibliographic coupling was performed for documents with at least 10 citations, and the largest connected component was used to visualize the main intellectual structure of the field.

In the network visualizations, node size represented the weight of an item, while links and total link strength reflected the relationships and overall connectivity among items. Colors represented clusters of closely related items identified by the VOSviewer clustering algorithm.

Finally, the included publications were classified according to the primary dental discipline in which the virtual reality or haptic simulation application was used. Classification was based on the title, abstract, and keywords of each publication. Each study was assigned to a single primary category according to its main educational application. The categories included restorative/operative dentistry, endodontics, oral surgery/implantology, prosthodontics, pediatric dentistry, oral and maxillofacial radiology, periodontology, orthodontics, and general/multidisciplinary preclinical dental education.

RESULTS

Study Selection and Publication Trends

The initial Scopus search identified 555 records. After restricting the results to English-language articles, 392 publications remained and were screened according to the predefined eligibility criteria. Following the exclusion of 216 records that did not meet the inclusion criteria, 176 original research articles were included in the final bibliometric analysis.

The included publications covered the period from 2003 to 2026 and received a total of 3,818 citations, corresponding to an average of 21.69 citations per publication. The annual number of publications remained relatively low during the earlier years but increased markedly in recent years. The largest annual number of publications was recorded in 2025, with 45 publications (25.6%), while a further 32 articles (18.2%) had been published by July 13, 2026. Overall, 96 of the 176 publications (54.5%) were published between 2024 and 2026 (**Figure 1**).

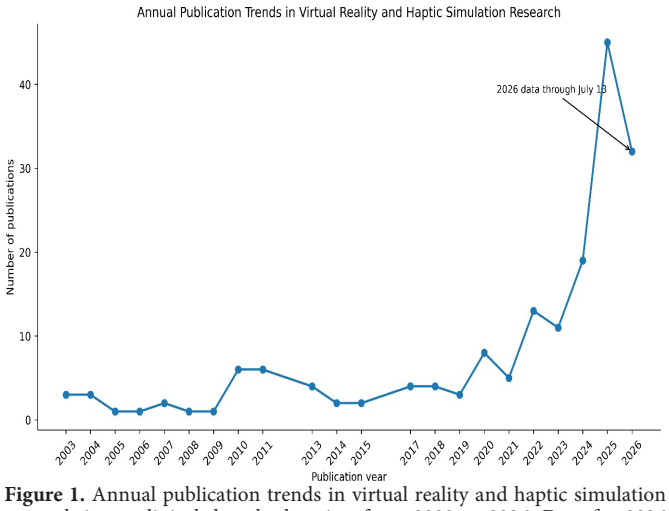

Figure 1. Annual publication trends in virtual reality and haptic simulation research in preclinical dental education from 2003 to 2026. Data for 2026 include publications indexed up to July 13, 2026

Leading Journals

The 176 publications were distributed across 59 journals. The Journal of Dental Education was the leading source, with 40 publications (22.7%) and 1,133 citations, followed by the European Journal of Dental Education with 26 publications (14.8%) and 778 citations, and BMC Medical Education with 23 publications (13.1%) and 272 citations. Together, these three journals accounted for 89 publications, representing 50.6% of the entire dataset. The International Endodontic Journal ranked fourth with eight publications, followed by Dentistry Journal with seven and BMC Oral Health with five publications. The number of publications and citation performance of the leading journals are presented in **Table 1**.

Leading Countries and International Collaboration

The included publications involved contributions from 55 countries. China was the most productive country, with 41 publications, followed by the United States with 24 and the United Kingdom with 18. Turkiye ranked fourth with 11 publications, while Germany, Saudi Arabia, Spain, and Thailand each contributed 10 publications.

Table 1. Publication output and citation performance of the leading journals in virtual reality and haptic simulation research in preclinical dental education

Rank	Journal	TP	TC	C/P
1	Journal of Dental Education	40	1,133	28.32
2	European Journal of Dental Education	26	778	29.92
3	BMC Medical Education	23	272	11.83
4	International Endodontic Journal	8	221	27.62
5	Dentistry Journal	7	64	9.14
6	BMC Oral Health	5	48	9.60
7	Journal of Dental Sciences	3	61	20.33
8	Virtual Reality	3	40	13.33
9	Frontiers in Oral Health	3	7	2.33
10	Artificial Intelligence in Medicine	2	105	52.50

TP: Total publications, TC: Total citations, C/P: Citations per publication

For the country-level co-authorship analysis, a minimum threshold of five publications per country was applied. Seventeen countries met this criterion, of which 16 formed the largest connected network. The network comprised three clusters, 60 links, and a total link strength of 83. The United Kingdom had the highest total link strength (TLS=24), followed by Australia and the United States (TLS=16 each). China had a TLS of 11, while Turkiye had a TLS of 5. The country-level co-authorship network is presented in **Figure 2**.

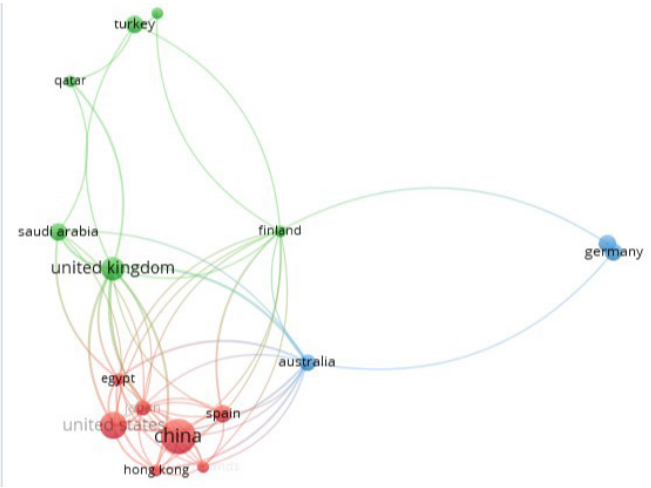

Figure 2. Network visualization of country-level co-authorship in virtual reality and haptic simulation research in preclinical dental education. Node size represents the number of publications, while links indicate co-authorship relationships between countries. Different colors represent clusters of closely connected countries

Most Cited Publications

The 10 most highly cited publications are presented in **Table 2**. The most cited study was "feedback and motor skill acquisition using a haptic dental simulator" by Al-Saud et al.,[13] with 127 citations. This was followed by "an evaluation of two dental simulation systems: virtual reality versus contemporary non-computer-assisted" by Jasinevicius et al.,[14] with 121 citations, and "evaluation of the introduction of a dental virtual simulator on the performance of undergraduate dental students in the pre-clinical operative dentistry course" by Murbay et al.,[15] with 117 citations.

Table 2. Most cited publications in virtual reality and haptic simulation research in preclinical dental education

Rank	First author	Year	Article title	Journal	TC
1	Al-Saud[13]	2017	Feedback and motor skill acquisition using a haptic dental simulator	European Journal of Dental Education	127
2	Jasinevicius[14]	2004	An evaluation of two dental simulation systems: virtual reality versus contemporary non-computer-assisted	Journal of Dental Education	121
3	Murbay[15]	2020	Evaluation of the introduction of a dental virtual simulator on the performance of undergraduate dental students in the pre-clinical operative dentistry course	European Journal of Dental Education	117
4	Buchanan[16]	2004	Experience with virtual reality-based technology in teaching restorative dental procedures	Journal of Dental Education	112
5	LeBlanc[17]	2004	A preliminary study in using virtual reality to train dental students	Journal of Dental Education	106

TC: Total citations

Keyword Co-occurrence Analysis

The keyword co-occurrence analysis identified 24 author keywords meeting the minimum threshold of five occurrences. The resulting network was organized into five clusters. Virtual reality was the most frequently occurring keyword (96 occurrences; TLS=181), followed by dental education (88 occurrences; TLS=167), haptics (21 occurrences; TLS=62), and simulation (18 occurrences; TLS=47). Other prominent terms included preclinical training (12 occurrences), virtual simulation (12 occurrences), and endodontics (11 occurrences). The relationships and clustering patterns among the author keywords are presented in **Figure 3A**.

The overlay visualization demonstrated differences in the average publication years of the identified keywords (**Figure 3B**). Earlier terms included skill acquisition (average publication year: 2008), computer-assisted instruction (2015), and computer simulation (2017), whereas more recent terms included preclinical training (2024), pediatric dentistry (2025), virtual simulation (2025), simulation training (2025), and haptic simulation (2025).

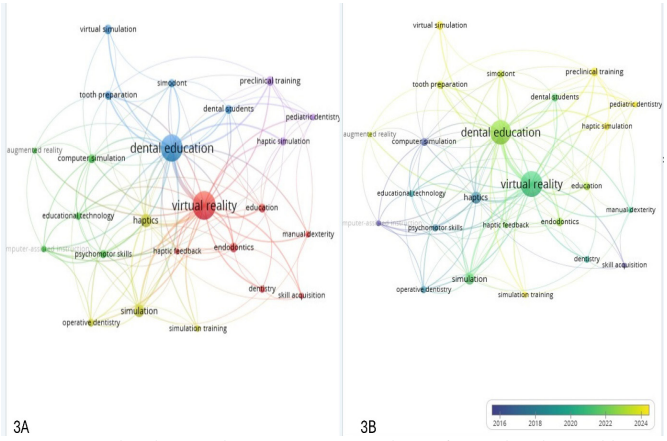

Figure 3. Author keyword co-occurrence analysis of virtual reality and haptic simulation research in preclinical dental education. (A) Network visualization showing relationships among frequently occurring author keywords, with node size reflecting keyword occurrence and colors indicating clusters. (B) Overlay visualization showing the temporal distribution of keywords according to their average publication year, with colors ranging from earlier to more recent publication years

Bibliographic Coupling Analysis

Bibliographic coupling analysis was performed to examine relationships among publications based on shared references. Of the publications with at least 10 citations, 83 formed the largest connected network and were grouped into eight clusters. The network comprised 1,392 links and a total link strength of 2,664 (**Figure 4**).

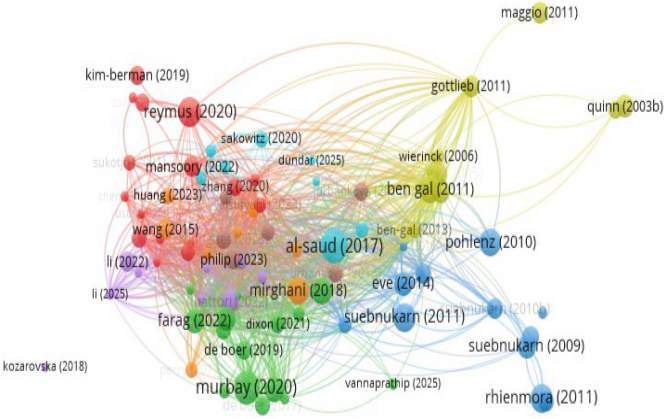

Figure 4. Network visualization of bibliographic coupling among publications on virtual reality and haptic simulation in preclinical dental education. Node size represents the relative weight of individual publications, links indicate bibliographic coupling relationships based on shared references, and colors represent clusters of bibliographically related publications

Among the publications in the network, Liu et al.[18] (2020) had the highest total link strength (TLS=185), followed by Rodrigues et al.[19] (2023) (TLS=134), Sheng et al.[20] (2022) (TLS=128), and Philip et al.[21] (2023) and Farag et al.[22] (2022) (TLS=127 each).

Distribution Across Dental Disciplines

The distribution of virtual reality and haptic simulation applications varied across dental disciplines. Restorative and operative dentistry represented the largest area of application, accounting for 64 publications (36.4%), followed by endodontics with 28 (15.9%) and oral surgery/implantology with 27 (15.3%). General or multidisciplinary preclinical dental education accounted for 17 publications (9.7%), while 16 studies (9.1%) focused on prosthodontics. Pediatric dentistry and oral and maxillofacial radiology each accounted for seven publications (4.0%), followed by periodontology with six (3.4%) and orthodontics with four (2.3%). The distribution across dental disciplines is presented in **Figure 5**.

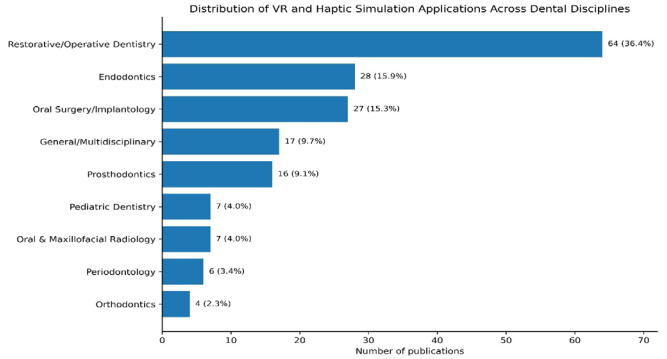

Figure 5. Distribution of virtual reality and haptic simulation applications across dental disciplines. Values indicate the number and percentage of publications assigned to each discipline

DISCUSSION

The present bibliometric analysis provides an overview of the development of research on virtual reality and haptic simulation in preclinical dental education. More than half of the included publications appeared between 2024 and 2026, indicating a marked increase in publication activity in recent years. The literature was concentrated in a relatively small number of dental and medical education journals, while publication patterns and international collaboration varied across countries. Keyword and bibliographic coupling analyses revealed the evolving structure of the field, and the discipline-based classification showed that restorative and operative dentistry represented the largest area of application, followed by endodontics and oral surgery/implantology.

This recent increase is consistent with broader developments in dental education research. Kandaswamy[7] identified virtual reality and educational technology among emerging topics in the dental education literature, while Chen et al.[8] similarly reported VR as an emerging research focus. More specifically, Hsu and Chang[2] observed an increase in publications on haptic and force-feedback technologies toward the end of their 2001-2022 study period, and Barriga-Yauri et al.[12] subsequently reported rapid growth in haptic simulation research between 2020 and 2025. Our findings extend these observations, with 54.5% of the included studies published between 2024 and 2026. This expansion may reflect the increasing availability of simulation technologies and growing interest in educational environments that support repeated practice and objective performance assessment before students progress to patient care.[1,23,24]

The concentration of publications in a relatively small number of journals reflects the close relationship between this research field and the broader dental education literature. The Journal of Dental Education, European Journal of Dental Education, and BMC Medical Education together accounted for more than half of all included publications. A similar pattern was reported by Matoug-Elwerfelli et al.,[3] who identified these journals among the most productive sources in their bibliometric analysis of VR research in restorative dentistry. The prominence of dedicated dental education journals is also consistent with previous bibliometric evaluations of the field.[7-9,25] The presence of publications in specialty-specific journals, particularly the International Endodontic Journal, further indicates that VR and haptic simulation research extends beyond general educational research into discipline-specific training.

The geographical distribution of publications demonstrated broad international interest, with contributions from 55 countries. China produced the highest number of publications, whereas the United Kingdom showed the highest total link strength in the country-level collaboration network, suggesting that scientific productivity and international connectivity do not necessarily develop in parallel. Previous studies have similarly identified China and the United States as major contributors to research on haptic and force-feedback technologies, while broader analyses of dental education have highlighted the substantial contribution of the United States and other established research environments.[2,7,8] Recent scientometric evidence has also indicated increasing collaboration within haptic simulation research.[12] Nevertheless, the variation in total link strength observed in the present study suggests that opportunities remain for broader international collaboration, particularly given potential differences in access to simulation technologies and approaches to preclinical training across educational settings.[2,7,8,12]

The temporal evolution of keywords illustrates changes in both the terminology and focus of the field. Earlier terms such as skill acquisition, computer-assisted instruction, and computer simulation reflect the educational and technical foundations of simulation-based training. In contrast, more recent terms including preclinical training, virtual simulation, simulation training, and haptic simulation indicate a move toward more specific descriptions of technology-supported educational applications. The emergence of pediatric dentistry among recent keywords may also reflect the expansion of these technologies into a broader range of dental disciplines. This pattern is consistent with previous bibliometric studies identifying VR and educational technologies as emerging areas in dental education.[2,7,9]

Bibliographic coupling revealed eight interconnected clusters within the literature, indicating that research on VR and haptic simulation draws on several related bodies of knowledge rather than a single educational theme. The relatively high connectivity among publications suggests substantial overlap in the references supporting different areas of research. Notably, several publications with high total link strength were relatively recent, indicating their central position within the current literature. These findings complement previous bibliometric analyses showing an increasingly interconnected research landscape surrounding haptic simulation and technology-supported dental education.[2,11]

One of the distinctive findings of the present study was the distribution of VR and haptic simulation applications across dental disciplines. More than one-third of the publications focused on restorative and operative dentistry, followed by endodontics and oral surgery/implantology. These disciplines rely heavily on psychomotor skills, hand-eye coordination, spatial perception, and precise instrument manipulation, which may make them particularly suitable for simulation-based training.[26-28] Procedures such as cavity and access cavity preparation, implant placement, and surgical procedures can be practiced repeatedly within virtual environments while allowing structured performance feedback.[29,30] Previous literature has similarly identified restorative dentistry and endodontics among the common applications of VR and haptic technologies.[1,3-6] The present study extends these findings by quantitatively demonstrating how publications are distributed across dental disciplines and highlighting areas in which these technologies have been less extensively investigated.

Limitations

The findings of this study should be interpreted in light of several limitations. The analysis was based exclusively on Scopus, and publications indexed only in other databases may therefore not have been captured. Restricting the search to English-language original research articles may also have excluded relevant literature. Citation-based indicators are influenced by publication age, giving earlier studies more time to accumulate citations. Moreover, citation counts do not necessarily reflect the scientific quality or methodological rigor of individual publications and may also be affected by journal visibility, self-citation practices, and differences in

citation behavior across disciplines. Bibliometric network analyses may also be affected by the search strategy, selected thresholds, and consistency of bibliographic metadata. Although a thesaurus file was used to merge synonymous or closely related keywords, variations in terminology may still have influenced the analysis. Finally, publications were classified according to their primary dental discipline; therefore, studies involving overlapping applications were assigned to a single category. These considerations should be taken into account when interpreting the research patterns identified in this study.

CONCLUSION

This bibliometric analysis provides a broad overview of the development of research on virtual reality and haptic simulation in preclinical dental education. The marked increase in publications in recent years demonstrates the growing interest in technology-supported approaches to dental training. The literature was concentrated primarily in dental and medical education journals, with China, the United States, and the United Kingdom among the leading contributors, although patterns of research productivity and international collaboration differed across countries. Keyword and bibliographic coupling analyses demonstrated an evolving research landscape, while the discipline-based analysis showed that restorative and operative dentistry, endodontics, and oral surgery/implantology were the most extensively investigated areas. Overall, the findings provide a structured overview of the current research landscape and may help identify less explored dental disciplines and opportunities for broader international collaboration in future research.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was based exclusively on publicly available bibliographic data and did not involve human or animal participants, clinical interventions, biological materials, or identifiable personal data. Therefore, ethics committee approval was not required.

Informed Consent

As the study did not involve human participants or identifiable personal data, informed consent was not applicable.

Conflict of Interest

The author declares no conflict of interest related to this study.

Financial Disclosure

The author received no financial support for the conduct, authorship, or publication of this research.

Author Contributions

The author was solely responsible for the study conception and design, data collection, analysis and interpretation, and preparation of the manuscript.

Editor Note

Sema Yazıcı Akbıyık is a member of the Editorial Board of this journal. She was not involved in the editor assignment, reviewer selection, peer review process, or editorial decision for this manuscript. The peer review process was managed independently by another editor.

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The effects of cigarette smoking on gingival phenotype and clinical periodontal parameters

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ABSTRACT

Aims: The aim of this study was to evaluate the effects of cigarette smoking on the gingival phenotype and to investigate the relationship between gingival thickness (GT), keratinized tissue width (KTW) and clinical periodontal parameters in smokers.

Methods: A total of 30 systemically healthy volunteers, including 15 smokers (group S) and 15 non-smokers (group NS), were enrolled in the study. GT, KTW and clinical periodontal parameters such as Plaque Index (PI), Gingival Index (GI), probing depth (PD), and bleeding on probing (BOP) were evaluated in the maxillary anterior and first molar regions. GT was measured using the transgingival probing method with a digital caliper (±0.01 mm accuracy). The KTW was determined by measuring the distance from the gingival margin to the mucogingival junction at the mid-buccal site. Data was analyzed using IBM SPSS Statistics 25.0 software.

Results: In the smoking group, GT and KTW values were significantly higher compared to the non-smoking group ($p<0.001$ and $p<0.05$, respectively). The plaque index was also significantly higher among smokers ($p<0.05$), whereas no significant differences were observed between the groups in terms of GI, PD, and BOP values ($p>0.05$).

Conclusion: The findings of this study indicate that cigarette smoking leads to an increase in gingival thickness and plaque accumulation. Smoking is an important environmental factor that adversely affects the gingival phenotype, both structurally and functionally. It may result in a gingival phenotype that appears thick and fibrotic but is biologically compromised, with reduced vascularity, healing, and defense capacity. These results emphasize the importance of considering the history of smoking in periodontal treatment planning and in maintaining periodontal health.

Keywords: Gingival phenotype, periodontal health, smoking

INTRODUCTION

The term phenotype is used to describe anatomical characteristics that can vary over time due to external influences such as environmental factors and clinical interventions, whereas biotype refers to tissue characteristics genetically determined by a specific genotype. The gingival phenotype encompasses both gingival thickness (GT) and keratinized tissue width (KTW), integrating not only the individual's gingival biotype but also environmental influences that may cause temporal variations.[1-3] In recent years, the clinical importance of gingival phenotype has increased due to its critical role in treatment planning, aesthetic outcomes, and long-term tissue stability.[4,5] Different gingival phenotypes exhibit variable biological responses to inflammation, trauma, and parafunctional habits and may lead to distinct outcomes in esthetic restorative procedures.[2] Hwang and Wang[6] suggested that the durability of thick soft tissues is primarily determined by a high-volume extracellular matrix, dense collagen content, and increased vascularity.

Accordingly, several individual and environmental factors such as age, gender, periodontal disease history, parafunctional habits, and smoking have been reported to influence the morphological and biological properties of the gingival phenotype. Among these factors, smoking is of particular importance due to its widespread prevalence and multifaceted impact on periodontal tissues.[7-9] Cigarette smoking is one of the strongest environmental risk factors in the development and progression of periodontal diseases. Numerous clinical and epidemiological studies have demonstrated that smokers exhibit significantly higher prevalence of gingival inflammation, clinical attachment loss, alveolar bone resorption, and tooth loss compared to non-smokers.[10-12] Exposure to tobacco smoke alters the subgingival microbial composition, resulting in a more pathogenic microbiota. Biofilms from smokers have been shown to be dominated by anaerobic species such as *Porphyromonas gingivalis*, *Tannerella forsythia*, and *Treponema denticola*, which promote bacterial toxins and proteases that mediate periodontal tissue destruction.[13,14]

Smoking has also been associated with distinct histopathological changes in the gingival epithelium,

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including increased epithelial thickness and basal cell hyperplasia.[15,16] Another notable finding is the suppression of the inflammatory response to plaque accumulation and the reduced incidence of bleeding on probing among smokers. Studies reporting decreased gingival bleeding in smokers have attributed this to the modulation of the host immune response by tobacco products.[17]

Considering these findings, careful assessment of the gingival phenotype has become an essential component of periodontal treatment planning. Therefore, evaluating the relationship between smoking and gingival phenotype in the general population is clinically important for maintaining periodontal health and improving treatment outcomes.[18] However, clinical studies directly investigating the impact of smoking on the gingival phenotype remain limited. The present study aims to evaluate the gingival phenotype in smokers and to investigate its influence on specific clinical periodontal parameters.

METHODS

Ethics

The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the İnönü University Non-interventional Clinical Researches Ethics Committee (Date: 18.11.2025, Decision No: 2025/8571) prior to its initiation. Before the study, all participants were informed in detail about their current condition and the study protocol, and both verbal and written informed consent were obtained.

Study Design

This cross-sectional and comparative study included volunteer participants who applied to the Department of Periodontology, Faculty of Dentistry, İnönü University, and met the predetermined inclusion criteria. Based on the study by Manasa et al.[19] a total of 30 systemically and periodontally healthy individuals aged between 24 and 43 years were enrolled, with 15 participants in each group. Participants with at least 20 natural teeth, including the maxillary and mandibular anterior teeth and first molars, were selected and divided into two groups: smokers (group S, n=15) and non-smokers (group NS, n=15). In both groups, the maxillary anterior and first molar teeth were examined in terms of GT, KTW and clinical periodontal parameters including PI, GI, BOP and PD. Plaque accumulation was assessed using the Silness and Löe PI,[20] while gingival inflammation was evaluated using the Löe and Silness GI.[21] For both indices, four surfaces of each examined tooth (buccal, palatal, mesial, and distal) were evaluated. The PI was scored as follows: 0=no plaque; 1=a thin film of plaque detectable only by running a probe across the tooth surface; 2=moderate, visible plaque accumulation; 3=abundant plaque accumulation. The GI was scored as follows: 0=normal gingiva; 1=mild inflammation without bleeding on probing; 2=moderate inflammation with redness, edema, and bleeding on probing; 3=severe inflammation with marked edema, ulceration, and a tendency toward spontaneous bleeding. For each tooth, the scores obtained from the four surfaces were averaged to calculate the PI and GI scores. BOP was recorded as present or absent following periodontal probing and expressed as a percentage of sites.[22] GT was measured at a point 1.5 mm apical to the gingival margin by inserting an endodontic spreader perpendicularly into the gingiva until bone contact was achieved. The penetration depth was measured with a digital caliper (accuracy: 0.01 mm). The KTW was determined by measuring the distance from the gingival margin to the mucogingival junction at the mid-buccal surface of each tooth, using the same instruments.

All measurements were performed twice for each site by the same calibrated examiner, and the mean of the two values was recorded for analysis.

Inclusion criteria were: Age ≥18 years; systemically and periodontally healthy status; for the smoker group, smoking at least 15 cigarettes per day for a minimum of 5 years; for the non-smoker group, no history of smoking; KTW >2 mm; and not being pregnant or lactating for female participants.

Exclusion criteria included: Use of medications affecting gingival or periodontal tissues; history of systemic diseases such as diabetes mellitus; bruxism; presence of gingival recession in the examined teeth; history of orthodontic treatment; restorative material in the examined area; or previous diagnosis of periodontal disease or periodontitis.

Statistical Analysis

A theoretical power analysis was performed using the G*Power 3.1 software. Assuming a type I error rate (α) of 0.05 and a statistical power (1-β) of 0.80, a total sample size of 30 participants (15 per group) was determined to be sufficient to detect a significant difference between groups. Statistical analyses were conducted using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA). The normality of distribution for continuous variables was assessed using the Shapiro-Wilk test, and the homogeneity of variances was evaluated using Levene's test. When parametric assumptions were met, comparisons between the two independent groups were performed using the independent samples t-test. For variables that did not show a normal distribution, the Mann-Whitney U test was applied. Categorical variables were compared using the Chi-square test. A p-value of less than 0.05 was considered statistically significant for all analyses.

RESULTS

A total of 30 participants, including 14 females and 16 males, were included in the study. The mean age of the participants was 31.05±2.5 years in the smoking group and 30.91±3.0 years in the non-smoking group, with no statistically significant difference between the groups (p=0.74). The gender distribution was equal in both groups (female/male ratio: 7/8) as shown in **Table 1**.

Table 1. Demographic characteristics of the study groups

		S (n=15)	NS (n=15)	p
Age (Md±SD)		31.05±2.5	30.91±3.0	0.842[1]
Gender, n (%)	Female	7 (46.7%)	7 (46.7%)	1.000[2]
	Male	8 (53.3%)	8 (53.3%)	

One-way ANOVA test, Chi-square test (S: >5 years; ≥15 cigarettes/day) ($p<0.05$). S: Smokers, NS: Non-smokers, Md: Mean, SD: Standard deviation, ANOVA: Analysis of variance

The comparative results of clinical periodontal parameters between smokers and non-smokers are presented in **Table 2**. The mean PI was 1.98±0.25 in smokers and 1.45±0.30 in non-smokers, indicating a statistically significant difference (p<0.05). The mean GI values were 0.95±0.15 and 0.90±0.18

in groups S and N, respectively, with no significant difference observed (p>0.05).

Table 2. Comparison of clinical periodontal parameters between smokers and non-smokers

	S (n=15)	NS (n=15)	p
PI	1.98±0.25	1.45±0.30	<0.001*
GI	0.95±0.15	0.90±0.18	0.41
PD	2.85±0.30	2.80±0.32	0.66
BOP	10.2±2.4	11.4±2.6	0.20

Shapiro-Wilk test, Mann-Whitney U test, Levene's test (*p<0.05) (S: >5 years; ≥15 cigarettes/day). S: Smokers, NS: Non-smokers, PI: Plaque Index, GI: Gingival Index, PD: Probing depth, BOP: Bleeding on probing

When PD was evaluated, the mean PD was 2.85±0.30 mm in smokers and 2.80±0.32 mm in non-smokers, showing no statistically significant difference (p>0.05). Similarly, bleeding on probing (BOP) values were 10.2±2.4% in smokers and 11.4±2.6% in non-smokers, and the difference was not statistically significant (p>0.05).

Values for GT and KTW are presented in **Table 3**. Both GT and KTW were significantly higher in smokers (1.77±0.28 mm and 2.54±0.42 mm, respectively) compared to non-smokers (1.25±0.19 mm and 2.31±0.23 mm) (p<0.001; p<0.05).

Table 3. Comparison of gingival thickness and keratinized gingival width between groups

	S (n=15)	NS (n=15)	p
GT	1.77±0.28	1.25±0.19	0.0001
KGW	2.54±0.42	2.31±0.23	0.019*

Independent samples t-test, Mann-Whitney U test (*p<0.05). S: Smokers, NS: Non-smokers, GT: Gingival thickness, KGW: Keratinized gingival width

Pearson correlation analyses between GT, KTW, and clinical periodontal parameters are summarized in **Table 4**. A positive correlation was observed between GT and PI, while GT showed a negative correlation with BOP. KTW was also positively correlated with PI.

Table 4. Correlation between gingival phenotype parameters and clinical periodontal parameters

	PI	GI	BOP
GT	r=0.42, p=0.02*	r=0.10, p=0.59	r=-0.36, p=0.04*
KGW	r=0.39, p=0.03*	r=0.12, p=0.52	r=-0.18, p=0.34

Pearson correlation analysis (*p<0.05). PI: Plaque Index, GI: Gingival Index, BOP: Bleeding on probing, GT: Gingival thickness, KGW: Keratinized gingival width

DISCUSSION

This study was conducted to evaluate the effects of cigarette smoking on the gingival phenotype and clinical periodontal parameters. According to the findings, both GT and KTW values were significantly higher in smokers compared to non-smokers. In addition, the PI was found to be significantly higher among smokers, whereas no statistically significant differences were observed between the groups in terms of GI, PD or BOP.

The gingival phenotype is defined by the buccolingual dimension of the gingiva and the width of the keratinized tissue. This concept encompasses not only genetically determined tissue characteristics but also features that may be altered by environmental factors and clinical interventions.[19] A systematic review on gingival morphology categorized gingival biotypes into three main groups: thin scalloped, thick flat, and thick scalloped. GT, KTW and bone morphotype are considered the three key parameters for classifying these biotypes, and they play an essential role in the development or progression of mucogingival defects.[23]

The gingival phenotype is further influenced by tissue thickness, degree of vascularization, regenerative capacity, and the immune response to inflammatory stimuli, all of which directly affect the outcome of periodontal therapy.[2] Among the environmental factors influencing the gingival phenotype, cigarette smoking not only exerts deleterious effects on gingival and periodontal tissues at the cellular level but also impairs the healing process, thereby reducing the response to periodontal treatment.[24]

Nicotine and other toxic components present in cigarettes lead to a reduction in gingival vascularity, decreased cellular oxygenation, and impaired regenerative capacity of connective tissue cells.[25] In addition, smoking induces histopathological changes such as epithelial hyperplasia, increased keratinization, and suppression of the inflammatory response, resulting in a thickened gingival phenotype.[26] However, clinical studies directly investigating the association between smoking and gingival phenotype remain limited. In this context, the present study aimed to assess the effects of cigarette smoking on the gingival phenotype. Our findings demonstrated that both GT and KTW were significantly greater in smokers than in non-smokers.

In the study conducted by Birlabose et al.,[27] a significant increase in GT was observed among smokers. The authors suggested that nicotine may enhance cellular proliferation within gingival tissues, influencing epithelialization and potentially contributing to the thicker gingival phenotype observed in smokers.[28] Similarly, a study using the transgingival probing method reported that GT was significantly greater in smokers in both buccal and interdental regions.[29] Nevertheless, this thickening has been suggested to represent not a healthy tissue increase but a pathological thickening caused by epithelial hyperkeratosis, inflammatory edema, and fibrotic alterations.[25] Therefore, smoking-induced phenotypic changes should be considered as an adverse adaptation rather than a protective mechanism for tissue stability.

In the present study, the PI values were significantly higher in smokers compared to non-smokers. This finding aligns with previous literature indicating that smoking negatively affects oral hygiene and predisposes to increased plaque accumulation. Smoking has been reported to promote plaque retention on tooth surfaces by altering salivary composition and pellicle formation, thereby facilitating oral biofilm development. Furthermore, inadequate oral hygiene habits commonly observed among smokers have also been identified as a contributing factor.[30,31]

In our study, no statistically significant differences were found between the groups in other periodontal parameters such as GI, PD, and BOP. This may be attributed to the generally healthy periodontal condition of the participants included in the study, as well as to the suppressive effect of smoking on clinical signs of gingival inflammation, which may mask inflammatory findings.[32] The inclusion of young and periodontally healthy participants in this study aimed

to minimize potential confounding variables other than smoking. However, several studies have reported higher GI and BOP values in non-smokers compared to smokers.[29,33,34] These findings have been attributed not only to the vasoconstrictive effects of smoking on the marginal gingival vasculature but also to the poorer oral hygiene frequently observed among smokers.[17] In the present study, although the PI values were significantly higher in smokers, no significant difference was found between the two groups regarding GI. This result can be explained by the vasoconstrictive effects of smoking on periodontal vascular tissues and the inhibition of local inflammatory mediator release.[35]

Limitations

Among the limitations of this study are the relatively small sample size and the lack of long-term follow-up data due to its cross-sectional design. Therefore, to better understand the effects of smoking on the gingival phenotype, future research should include larger sample sizes and multi-center, prospective studies with long-term follow-up periods.

CONCLUSION

The findings of this study demonstrate that cigarette smoking affects the gingival phenotype by increasing GT. Additionally, higher plaque accumulation was observed among smokers; however, no significant differences were detected in gingival inflammation parameters. This suggests that smoking may mask clinical signs of inflammation in periodontal tissues.

Although smokers may exhibit a clinically thick and fibrotic gingival appearance, compromised vascularization may result in reduced healing capacity and impaired host defense response. Considering smoking habits during clinical evaluation is therefore crucial for accurate assessment of periodontal health and effective planning of surgical and therapeutic procedures.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was approved by the İnönü University Non-interventional Clinical Researches Ethics Committee (Date: 18.11.2025, Decision No: 2025/8571).

Informed Consent

Written informed consent was obtained from all individual participants prior to their inclusion in the study. Participants were fully informed about the study's aims, procedures, potential risks and benefits, and their rights-including the right to withdraw at any time without consequence. All participants voluntarily signed a written informed consent form.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

Financial Disclosure

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Author Contributions

Concept: ÜGÖ, VET; Design: ÜGÖ, VET; Control: ÜGÖ, VET; Resources: ÜGÖ, VET; Materials: ÜGÖ, VET; Data Collection and/or Processing: ÜGÖ, VET; Analysis and/or Interpretation: ÜGÖ, VET; Literature Review: ÜGÖ, VET; Writing the Article: ÜGÖ, VET; Critical Review: ÜGÖ, VET.

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Identification of bioaerosol composition in preclinical dental laboratories using MALDI-TOF MS

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ABSTRACT

Aims: The grinding and polishing procedures carried out during dental training result in the release of high levels of particulate matter and microorganisms into the environment. This study aimed to assess the microbial air quality in the preclinical laboratory environment and to identify the predominant species using matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS).

Methods: Sampling was performed before and during the preclinical session using the passive deposition method. The isolated microorganisms were identified using MALDI-TOF MS.

Results: The total microbial load was 22.67±1.15 CFU/plate prior to the preclinical session, whereas during the session it rose to 169.00±13.86 colony forming units (CFU)/plate, representing an approximately 7.5-fold increase. During the study, fungal pathogens such as *Aspergillus* spp. and *Candida tropicalis*, as well as *Staphylococcus* and *Micrococcus* species, were found to be predominant.

Conclusion: Laboratory activities increase the microbial load by approximately 7.5-fold. This highlights the importance of adequate ventilation and the use of personal protective equipment.

Keywords: Bioaerosol, air pollution, preclinical training, MALDI-TOF MS

INTRODUCTION

Dental training involves intensive practical sessions in preclinical laboratories. The high-speed rotary instruments used during this process lead to the formation of bioaerosols, which consist of liquid and solid particles containing microbial agents. Bioaerosols are microscopic particles that can remain suspended in the air for long periods and reach the depths of the lungs (alveoli) via the respiratory tract.[1]

Preclinical laboratories are areas where the risk of cross-contamination is high due to the large number of students working simultaneously. The literature reports that particulate matter released into the environment during dental procedures is not merely a physical contaminant but also acts as a carrier (vector) for pathogenic microorganisms. In particular, dust-generating procedures such as acrylic restoration and tooth cutting significantly increase the microbial load (CFU/plate) in the environment.[2] The aim of this study is to characterize the microbial diversity in a dental faculty preclinical laboratory and to assess the microbial load in the ambient air using the passive deposition method. It was hypothesized that active acrylic trimming procedures would increase both the airborne microbial load and microbial diversity in the preclinical laboratory compared with the baseline period.

METHODS

Ethics

This study was conducted as an in vitro environmental microbiological assessment in a preclinical dental laboratory. No human participants, patient data, human biological samples, or animal subjects were involved. Therefore, according to institutional practice, ethics committee approval was not required for this study.

Study Design

The study was conducted at the Preclinical Laboratory of Dicle University. The preclinical laboratory had a capacity of approximately 150 students, and 70 students were present during the experimental session. During the active sampling period, the students performed acrylic trimming procedures using micromotors and rotary burs. The exact operating speed (rpm) of the micromotors was not recorded. Local suction systems located beneath each workstation were in operation during the procedures. The air-conditioning system was operating, and the doors and windows were open throughout the sampling period. Room temperature and relative humidity were not recorded.

Passive air sampling was performed at three designated locations on the same day. Baseline sampling was conducted

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in the morning, following routine cleaning of the laboratory and before the students entered and laboratory activities commenced. Petri dishes were placed on work surfaces approximately 1 m above floor level and exposed for 1 h. Sampling was subsequently repeated for 1 h at the same designated locations while 70 students were performing acrylic trimming procedures. One sampling point was located on the academic staff desk, approximately 1.5 m from the student working area, whereas the other two sampling points were located on the student workstations closest to the academic staff desk. The sampling points were approximately 1.5 m apart.

The passive settling method was used to determine the microbial load in the ambient air. This method is based on the principle that microorganisms settle onto the surface of the culture medium under the influence of gravity.[3]

As part of the passive settling method used to assess the load of microorganisms in the air, microorganisms that settled onto culture media left exposed for specific periods were isolated following incubation. Pure cultures obtained from the developing colonies were identified in the microbiology laboratory using matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS) (Zybio Inc., China), a method based on protein fingerprint analysis.[4,5] The results obtained enabled the qualitative and species-level assessment of microbial contamination in ambient air.

For sampling purposes, blood agar was used to assess total bacterial count and haemolytic properties; EMB agar was used for the selective isolation of gram-negative bacteria; and Sabouraud dextrose agar was used to detect fungal (yeast and mould) contamination.

Following sampling, the Petri dishes were transferred to the microbiology laboratory; bacteria were incubated at 37°C for 24-48 hours, whilst fungi were incubated at 25°C for 5-7 days. At the end of incubation, the developed colonies were counted, and the results were recorded as colony forming units (CFU/plate). Although EMB agar was used for the selective isolation of gram-negative bacteria, as these microorganisms also grew on blood agar, species-level identification and colony counting were carried out using isolates obtained from colonies that developed on blood agar.

Statistical Analysis

Descriptive statistics were expressed as mean±standard deviation (SD). Since measurements before and during acrylic trimming were obtained from the same three sampling locations, the observations were treated as paired. The normality of the paired differences was assessed using the Shapiro-Wilk test. No statistically significant deviation from normality was detected ($p=0.132$); therefore, microbial loads before and during acrylic trimming were compared using a paired-samples t-test. Statistical significance was set at $p<0.05$. Statistical analyses were performed using Python with the SciPy statistical package.

RESULTS

Measurements carried out in a preclinical laboratory setting revealed significant differences in microbial load and diversity before and during laboratory activities.

It was determined that during preclinical procedures, the total microbial load increased from 22.67±1.15 CFU/plate to 169.00±13.86 CFU/plate, representing an approximate 7.5-fold increase. Statistical analysis between the groups revealed that the difference was statistically significant ($p=0.003$).

Prior to the preclinical session, a limited number of bacterial species were isolated, while no fungal growth was detected. The main microorganisms isolated during this period were *Staphylococcus hominis*, *Micrococcus luteus*, *Staphylococcus epidermidis*, and *Bacillus* species (**Table 1**).

Table 1. CFU/plate distribution of microorganisms isolated prior to preclinical laboratory testing

Microorganism	Plate 1 (CFU/plate)	Plate 2 (CFU/plate)	Plate 3 (CFU/plate)
Staphylococcus hominis	7	4	7
Micrococcus luteus	7	5	10
Staphylococcus epidermidis	4	8	3
Bacillus spp.	2	4	2
Mesobacillus thioparans	1	0	0
Pseudarthrobacter oxydans	2	1	0
Oerskovia turbata	1	0	0

CFU: Colony forming units

In contrast, a marked increase in both microbial diversity and colony density was observed during preclinical trials (**Figure**). During this period, in addition to species such as *Micrococcus luteus*, *Staphylococcus pasteuri*, *Staphylococcus xylosus*, *Staphylococcus epidermidis*, *Staphylococcus haemolyticus*, and *Streptococcus mitis/oralis*, environmental and potentially pathogenic microorganisms (*Escherichia coli*, *Pseudomonas oryzihabitans*, and *Trueperella pyogenes*) were also isolated (**Table 2**).

Before Preclinical Training **During Preclinical Training**

Figure. Appearance of colonies obtained using the passive agar plate method in a preclinical laboratory setting

Table 2. Distribution of microorganisms isolated during preclinical laboratory testing, expressed as CFU per plate

Microorganism	Plate 1 (CFU/plate)	Plate 2 (CFU/plate)	Plate 3 (CFU/plate)
Micrococcus luteus	45	80	50
Staphylococcus pasteuri	15	10	18
Staphylococcus xylosus	10	7	8
Staphylococcus epidermidis	15	20	28
Staphylococcus haemolyticus	31	15	10
Streptococcus mitis/oralis	15	5	7
Bacillus subtilis	3	8	11
Corynebacterium callunae	3	2	4
Moraxella osloensis	9	18	7
Pseudomonas oryzihabitans	1	3	1
Staphylococcus warneri	8	7	13
Escherichia coli	2	1	0
Trueperella pyogenes	1	2	0
Aspergillus spp.	2	5	4
Candida tropicalis	1	2	0

CFU: Colony forming units

Furthermore, fungal microorganisms not detected prior to the preclinical phase emerged during the procedures; in particular, species of *Aspergillus* spp. and *Candida tropicalis* were isolated.

The data obtained indicate that during laboratory activities, not only did the microbial load increase, but the diversity of microorganisms present in the environment also expanded significantly (**Table 2**).

DISCUSSION

In this study, the effect of procedures carried out in a preclinical dental laboratory setting on microbial air contamination via bioaerosol formation was evaluated. The passive deposition method was used to determine the microbial load and bioaerosol diversity in the ambient air.

The findings revealed a significant increase in the microbial load during preclinical procedures. The average colony count prior to preclinical procedures was approximately 22.67±1.15 CFU/plate; this value rose to approximately 169.00±13.86 CFU/plate during preclinical procedures, demonstrating that laboratory activities significantly increased the biological load in the ambient air. This increase is consistent with studies reporting that aerosol and particle formation during dental procedures enhance microbial spread.[6,7]

Upon examining the distribution of microorganisms, it was observed that *Staphylococcus*, *Micrococcus*, and *Bacillus* species were predominant. These species are frequently reported in dental aerosol studies and are among the microorganisms that may be of human origin. However, the fact that species such as *Escherichia coli*, *Pseudomonas oryzihabitans*, and *Trueperella pyogenes* were detected only during preclinical procedures suggests that environmental contamination, as well as human sources, may be a factor in the environment.[7,8]

A particularly striking finding in this context is that, although certain microorganisms were not detected prior to the preclinical phase, they appeared in high concentrations only during the procedure. This suggests that these microorganisms were introduced into the environment via bioaerosols generated during laboratory activities, rather than originating from the ambient flora. Such a 'absence-to-presence' transition can be interpreted as a direct indicator of bioaerosol formation.[7]

The findings regarding fungal contamination are similarly noteworthy. While no fungal growth was detected prior to preclinical procedures, the isolation of *Aspergillus* spp. and *Candida tropicalis* during procedures suggests that fungal spores can remain airborne and become mobilized in the environment due to particle formation. This indicates that bioaerosols in dental laboratory environments contain not only bacterial but also fungal components.[9]

Increased microbial load and diversity pose a potential exposure risk, particularly for students working for extended periods in preclinical laboratories. Bioaerosols generated during procedures performed at close range are significant in terms of cross-contamination and respiratory exposure.[6] Furthermore, previous studies assessing airborne particles and microbial components have highlighted the potential occupational health risks associated with bioaerosol exposure in such environments.[7,10]

In light of these findings, it is important to enhance the effectiveness of ventilation systems in preclinical laboratory settings, utilize high-vacuum aspiration systems, and standardize the use of personal protective equipment. The implementation of engineering controls, such as air purification systems fitted with HEPA filters, may also contribute to improving ambient air quality.[2,6]

Recent studies have further emphasized the importance of monitoring and controlling aerosols in dental environments. Dental procedures may generate particles of varying sizes with a microbiological component, highlighting their potential relevance to cross-contamination in clinical environments.[11] In preclinical dental training settings, ventilation, air-conditioning, and evacuation strategies have also been investigated as important factors influencing indoor air quality during aerosol-generating procedures.[12] Furthermore, recent systematic evidence indicates that aerosol-control measures, particularly suction devices, can reduce microbial contamination generated during dental procedures.[13] These findings support the importance of appropriate ventilation and aerosol-control strategies in dental training environments where multiple individuals work simultaneously.

Limitations

The limitations of this study include the use of passive sampling methods and the limited duration of sampling. The relatively short sampling period may not fully capture temporal variations in microbial load and diversity throughout different laboratory sessions or time periods. In future studies, longer and repeated sampling periods, the use of active air sampling methods, and data obtained from larger sample groups would contribute to a more comprehensive assessment of microbial dynamics in dental laboratory environments.

CONCLUSION

This study demonstrates that procedures carried out in a preclinical dental laboratory setting significantly increase microbial air contamination via bioaerosol formation. A statistically significant increase was observed in both total colony count and microbial diversity during preclinical procedures; in particular, the fact that certain microorganisms appeared only during the procedures suggests that these species were introduced into the environment via bioaerosols. Furthermore, the isolation of fungal microorganisms that were not detected prior to the preclinical procedures indicates that particle formation may contribute to the suspension of fungal spores in the air during these procedures.

The findings indicate that preclinical laboratories are not merely educational environments but also high-risk work areas where potential exposure to bioaerosols is a concern. Consequently, the use of effective ventilation systems, the widespread adoption of high-vacuum aspiration systems, and the routine use of personal protective equipment are recommended.

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

Since the study was conducted without the participation of any living being, no written consent form was obtained.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

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Author Contributions

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Influence of polishing systems and thermal aging on the surface gloss of microhybrid and nanohybrid resin composites

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ABSTRACT

Aims: This study evaluated the effects of different polishing systems on the surface gloss of microhybrid and nanohybrid resin composites and the effect of thermal aging on gloss retention.

Methods: Ninety specimens of 3M™ Filtek™ Z250 and VOCO GrandioSO were assigned to Twist Dia (TD), Sof-Lex Disc (SD), or control groups (n=15). Thermal aging was performed for 15,000 cycles between 5°C and 55°C with a 30-second dwell time. Surface gloss was measured at baseline, after polishing, and after thermal cycling. Statistical significance was set at $p<0.05$.

Results: Polishing significantly increased surface gloss in both composites (all $p<.001$), whereas thermal aging significantly reduced gloss (all $p<.001$; Cohen's $d=2.32$-4.24). Immediately after polishing, TD and SD showed comparable gloss values ($p=1.000$), and composite type had no significant overall effect [$F(1.84)=3.02$, $p=.086$]. After thermal cycling, SD retained significantly higher gloss than TD ($p=.002$) and control ($p=.018$). Split-plot ANOVA showed significant effects of thermal cycling ($p<.001$, partial $\eta^2=.908$) and polishing system ($p<.001$, partial $\eta^2=.470$), with significant interactions between polishing system and thermal cycling and between composite type and thermal cycling (both $p<.001$).

Conclusion: Polishing increased surface gloss, whereas thermal aging substantially reduced it. SD demonstrated superior gloss retention after thermal aging, although TD and SD performed similarly immediately after polishing. Composite type did not significantly affect overall gloss but interacted with thermal aging.

Keywords: Composite resin, finishing and polishing, surface gloss, glossmeter, thermal aging

INTRODUCTION

Resin-based composites are widely used in direct restorative dentistry because of their favorable esthetic properties, adhesive potential, and versatility. The long-term esthetic performance of these materials, however, depends not only on their initial optical properties but also on their ability to maintain a smooth and glossy surface during service.[1,2] Surface gloss is an important optical parameter associated with the perception of smoothness and restoration quality, while deterioration of surface characteristics may increase light scattering and compromise the esthetic appearance of restorations.[1-4] Therefore, achieving and maintaining a high-gloss surface is an important objective of finishing and polishing procedures.

Finishing and polishing procedures play a critical role in establishing the final surface characteristics of resin composites. The effectiveness of a polishing procedure is influenced by the abrasive material, particle size, number of polishing steps, application protocol, and intrinsic characteristics of the resin composite.[3,4] In particular, filler size, morphology, distribution, hardness, and filler loading may affect the interaction between the abrasive and composite surface and consequently influence the final gloss. Recent studies have demonstrated that the performance of polishing systems is material-dependent, with differences in surface gloss observed among resin composites following the use of one-step, two-step, and multi-step polishing protocols.[5-8] These findings suggest that the classification of a composite alone may not adequately predict its response to a particular polishing system.

The maintenance of surface gloss following artificial aging is another clinically relevant consideration. Resin composites are exposed to repeated thermal fluctuations, moisture, mechanical stresses, and chemical challenges in the oral environment, which may induce degradation of the resin matrix-filler interface and alter surface characteristics over time. Thermocycling is therefore frequently used as an artificial aging method for evaluating the stability of restorative materials. Rocha et al.[9] demonstrated that thermocycling between 5°C and 55°C reduced the surface gloss of several resin composites, although the magnitude of the effect varied according to the material. More recent investigations have similarly shown that gloss retention following finishing and polishing may vary according to both the composite formulation and the polishing protocol.[8,9] Thus, a polishing

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system that produces a high initial gloss may not necessarily provide optimal gloss retention after aging.

Despite increasing interest in the optical performance of polished resin composites, the combined effects of polishing system, composite filler characteristics, and subsequent thermal aging on surface gloss remain insufficiently characterized. In particular, direct comparisons between a two-step diamond-impregnated spiral system and a conventional multi-step aluminum oxide disc system in microhybrid and nanohybrid composites, followed by evaluation of gloss retention after extensive thermal cycling, are limited. This is relevant because Filtek Z250 and GrandioSO differ substantially in filler characteristics and resin matrix composition, potentially resulting in different responses to polishing and thermal aging. Therefore, this study aimed to evaluate the effects of Twist Dia and Sof-Lex Disc polishing systems on the surface gloss of a microhybrid resin composite (Filtek Z250) and a nanohybrid resin composite (GrandioSO), and to assess changes in gloss following 15,000 thermal cycles. The null hypotheses were that (1) polishing system would not significantly affect surface gloss, (2) resin composite type would not significantly affect surface gloss, and (3) thermal aging would not significantly alter surface gloss.

METHODS

Ethics

Ethics committee approval was not required because this was an in vitro laboratory study conducted exclusively using commercially available resin composite materials, without involving human participants, human-derived biological specimens, or animals. All procedures were carried out in accordance with the ethical rules and the principles.

Study Design and Specimen Preparation

This in vitro study was designed to evaluate the effects of different polishing systems on the surface gloss of microhybrid and nanohybrid resin composites and to assess gloss retention following thermal aging. Two commercially available resin composites were investigated: a microhybrid composite (Filtek™ Z250; 3M ESPE, St. Paul, MN, USA) and a nanohybrid composite (GrandioSO; VOCO GmbH, Cuxhaven, Germany). The compositions and characteristics of the resin composites are presented in **Table 1**. The materials differed in filler type, filler loading, and resin matrix composition, allowing the influence of composite composition on surface gloss and gloss retention to be evaluated.

Specimen Size and Sample Size Calculation

A total of 90 resin composite specimens were prepared, consisting of 45 Filtek Z250 and 45 GrandioSO specimens. All specimens were fabricated using a standardized circular mold with an internal diameter of 8 mm and a thickness of 2 mm.

Sample size calculation was performed using G*Power software (version 3.1.9.2; Heinrich Heine University, Düsseldorf, Germany). Based on a previous study with a similar methodology, an effect size of 3.608 was determined. With a statistical power of 95% and a significance level (α) of 0.05, the minimum required sample size was calculated as eight specimens per group.[10] To increase the reliability and statistical power of the study, 15 specimens were included in each group, resulting in a total sample size of 90 specimens.

The specimens were randomly allocated according to resin composite type and surface treatment. For each composite, the specimens were divided into three groups (n=15): Twist Dia (TD), Sof-Lex Disc (SD), and an unpolished control group (K). Thus, six experimental subgroups were obtained, with 15 specimens in each subgroup.

Specimen Preparation

The specimens were prepared using a standardized procedure based on previously described methods. A circular plastic mold (8 mm in diameter and 2 mm in thickness) was placed on a glass slide and covered with a Mylar strip.[11] The resin composite was then placed into the mold and gently condensed to minimize the formation of voids. A second Mylar strip and a glass slide were placed over the uncured composite, and gentle pressure was applied to obtain a flat and uniform surface.

Polymerization was performed using a light-emitting diode (LED) curing unit (Valo X; Ultradent Products, South Jordan, UT, USA) with an irradiance of 1000 mW/cm². Each specimen was light-cured for 20 seconds from both the top and bottom surfaces. Following polymerization, the specimens were stored in distilled water at 37°C for 24 hours.

To standardize the initial surface conditions and remove the oxygen-inhibited layer, the upper surfaces of all specimens were roughened using the coarsest disc (80 µm) of the OptiDisc system (Kerr Corporation, Orange, CA, USA). This procedure was performed under dry conditions at 9000 rpm for 30 seconds. The bottom surfaces were marked with a scalpel to ensure consistent specimen orientation throughout the subsequent procedures.

Polishing Protocol

All polishing procedures were performed by a single experienced and calibrated operator using a low-speed micromotor with a contra-angle handpiece (NSK, Japan). Polishing was performed according to the manufacturers' recommendations regarding rotational speed, application time and sequence. A new polishing instrument was used for each specimen, and gentle, consistent manual pressure was maintained throughout the polishing procedures; however, the applied pressure was not objectively quantified.[12]

Table 1. Resin composites used in this study

Resin composite	Manufacturer	Color	Classification	Filler (wt.%)	Filler type	Matrix
Filtek™ Z250	3M ESPE, St. Paul, MN, USA	A2	Microhybrid	82	Zirconia/silica; 0.01-3.5 µm	Bis-GMA, UDMA, Bis-EMA, TEGDMA
GrandioSO	VOCO GmbH, Cuxhaven, Germany	A2	Nanohybrid	89	Glass ceramic filler (~1 µm), functionalized silicon dioxide nanoparticles (20-40 nm), pigments	Bis-GMA, Bis-EMA, TEGDMA

wt.%: Weight percentage, MN: Minnesota, USA: United States of America, µm: Micrometer, Bis-GMA: Bisphenol A-glycidyl methacrylate, UDMA: Urethane dimethacrylate, Bis-EMA: Ethoxylated bisphenol A dimethacrylate, TEGDMA: Triethylene glycol dimethacrylate, nm: Nanometer

In the TD group, specimens were polished using a two-step diamond-impregnated spiral system (Twist Dia; Kuraray, Japan). The coarse spiral (14 µm) was operated at 5000 rpm for 20 seconds in a counterclockwise direction, followed by the fine spiral (10 µm), which was applied at 2000 rpm for 20 seconds in the same direction. Both polishing steps were carried out under dry conditions without water cooling.

In the SD group, specimens were polished with a four-step aluminum oxide (Al_2O_3)-coated polishing system (Sof-Lex Disc; 3M, USA). Coarse (55 µm), medium (40 µm), fine (24 µm), and superfine (8 µm) discs were applied sequentially for 20 seconds each at 5000 rpm under dry conditions.

Following polishing, the specimens were rinsed with distilled water to remove residual debris and dried with oil-free compressed air. The control group received no polishing procedure.

Surface Gloss Measurement

Surface gloss was measured using a glossmeter (PCE-SGM60 Plus; PCE Instruments, Germany) with a 60° measurement geometry. Gloss values were recorded in gloss units (GU). Gloss measurements were performed at three experimental stages: before polishing (baseline), immediately after polishing, and after thermal aging. Before each measurement, the specimens were rinsed with distilled water and dried to remove surface debris and moisture. The specimens were positioned in a standardized manner to ensure that the same surface area was evaluated at each measurement stage. A custom-made black polytetrafluoroethylene (PTFE) mold with a thickness of 10 mm was positioned over each specimen to ensure proper alignment and minimize the influence of ambient and reflected light. Each specimen was measured three times by a single experienced operator, and the mean of the three measurements was used for statistical analysis.[13]

Thermal Aging

Following the post-polishing gloss measurements, all specimens were subjected to thermal aging using a thermocycling device. The specimens underwent 15,000 thermal cycles between 5°C and 55°C, with a dwell time of 30 seconds in each bath. The transfer time between the two baths was kept as short as possible and was controlled by the thermocycling device.[9] After completion of thermal cycling, the specimens were rinsed with distilled water and dried, and surface gloss was measured again using the same measurement protocol described above. The post-aging gloss values were compared with the baseline and post-polishing measurements to evaluate changes in surface gloss and gloss retention following thermal aging.

Statistical Analysis

All data analyses were performed using IBM SPSS Statistics, version 27.0 (IBM Corp., Armonk, NY, USA).

The gloss data obtained in this study were evaluated using a split-plot (mixed) three-way ANOVA, with composite type (GrandioSO/nanohybrid, Filtek Z250/microhybrid) and polishing system (Twist Dia, Sof-Lex Disc, unpolished control) treated as between-subjects factors, and thermal cycling (pre-thermal cycling/post-thermal cycling) treated as a two-level within-subjects (repeated-measures) factor because measurements were obtained from the same specimens. For the polished groups, the pre-thermal-cycling value entered into the mixed ANOVA was the measurement obtained immediately after polishing; for the unpolished control groups, the corresponding pre-thermal-cycling value was the baseline measurement because no polishing procedure was performed. The initial baseline measurements of the polished groups were not included as a third level in the mixed ANOVA; they were used separately to evaluate the immediate effect of polishing relative to the pre-polishing condition. Main effects (composite type, polishing system, thermal cycling) and two- and three-way interactions (composite type×polishing system, composite type×thermal cycling, polishing system×thermal cycling, composite type×polishing system×thermal cycling) were examined; between-subjects effects were tested against the between-subjects error term, while within-subjects effects were tested against the residual error term. Effect sizes were reported as partial eta squared (partial η^2). Paired-samples t-tests were used to compare gloss values before and after thermal cycling within each composite-polishing system combination, with effect sizes expressed as Cohen's d. Pairwise comparisons between polishing systems were performed using independent-samples t-tests following one-way ANOVA. Bonferroni correction was applied to control for type I error arising from multiple comparisons. Statistical significance was set at $p<.05$.

RESULTS

Descriptive Statistics

As shown in **Table 2**, polishing markedly increased gloss values in both composite materials compared to the baseline (unpolished) surfaces. In the VOCO group, mean gloss increased from 54.95±12.84 GU to 69.45±11.32 GU with Twist Dia, and from 43.65±16.38 GU to 66.32±14.43 GU with Sof-Lex. In the Z250 group, this increase reached from 43.69±10.63 GU to 81.04±15.93 GU for Twist Dia, and from 46.20±13.02 GU to 79.80±18.91 GU for Sof-Lex. A one-way ANOVA performed before thermal cycling revealed a significant difference among polishing systems ($F(2,87)=39.30$; $p<.001$); however, pairwise comparisons showed no significant difference between Twist Dia and Sof-Lex ($p=1.000$), while both systems produced significantly higher gloss than the control group ($p<.001$ for both comparisons).

Following thermal cycling, a marked and statistically significant loss of gloss was observed in all groups (paired t-tests, $p<.001$ for all groups; Cohen's d=2.32-4.24). According to the three-way split-plot ANOVA results, the main effect of thermal cycling was the most dominant finding of the study [$F(1.84)=829.70$; $p<.001$; partial $\eta^2=.908$], followed by the main effect of polishing system [$F(2.84)=37.29$; $p<.001$; partial $\eta^2=.470$]. The main effect of composite type alone did not reach significance [$F(1.84)=3.02$; $p=.086$].

The polishing system×thermal cycling interaction was significant [$F(2,84)=38.39$; $p<.001$], indicating that thermal cycling-induced gloss loss differed according to polishing system. Indeed, a one-way ANOVA performed after thermal cycling detected a significant difference among polishing systems [$F(2.87)=8.01$; $p<.001$], and the highest post-cycling gloss values in both composites were recorded in the Sof-Lex group (VOCO: 27.03±7.37 GU; Z250: 21.11±5.34 GU). In pairwise comparisons, Sof-Lex retained significantly more gloss than both Twist Dia ($p=.002$) and the control group ($p=.018$), whereas no significant difference was found

Table 2. Mean±SD, GU by composite, polishing system, and stage (n=15/cell)

Composite	Polishing system	Stage	Mean±SD (GU)	n
VOCO (nanohybrid)	Twist Dia	Baseline (pre-polish)	54.95±12.84	15
	Twist Dia	After polishing (pre-TC)	69.45±11.32	15
	Twist Dia	After thermal cycling	19.27±7.75	15
	Sof-Lex	Baseline (pre-polish)	43.65±16.38	15
	Sof-Lex	After polishing (pre-TC)	66.32±14.43	15
	Sof-Lex	After thermal cycling	27.03±7.37	15
	Control (unpolished)	Baseline (pre-TC)	45.33±9.99	15
	Control (unpolished)	After thermal cycling	18.52±4.44	15
Z250 (microhybrid)	Twist Dia	Baseline (pre-polish)	43.69±10.63	15
	Twist Dia	After polishing (pre-TC)	81.04±15.93	15
	Twist Dia	After thermal cycling	16.21±4.41	15
	Sof-Lex	Baseline (pre-polish)	46.20±13.02	15
	Sof-Lex	After polishing (pre-TC)	79.80±18.91	15
	Sof-Lex	After thermal cycling	21.11±5.34	15
	Control (unpolished)	Baseline (pre-TC)	44.99±10.86	15
	Control (unpolished)	After thermal cycling	20.26±6.64	15

SD: Standard deviation, GU: Gloss units, TC: Thermal cycling

between Twist Dia and the control group (p=.876). These findings indicate that Sof-Lex-polished surfaces were more resistant to thermal cycling-induced gloss loss compared to Twist Dia, whereas the initial gloss advantage achieved with Twist Dia was eliminated following thermal cycling. In addition, the composite type × thermal cycling interaction was also significant [F (1.84)=12.12; p<.001], suggesting that the two composites exhibited different patterns of gloss loss in response to thermal cycling (**Figure**; **Table 3**).

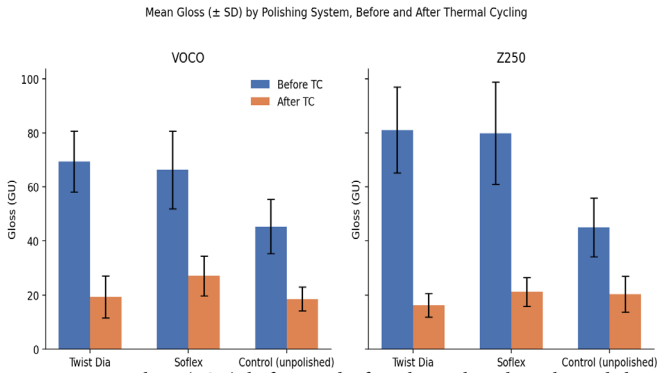

Figure. Mean gloss (±SD) before and after thermal cycling, by polishing system and composite

SD: Standard deviation

Key findings:

- **Thermal cycling (C):** Overwhelming main effect, F (1.84)=829.70, p<.001, partial η^2=.91-gloss dropped sharply after thermal cycling in every group.
- **Polishing system (B):** Large main effect, F (2.84)=37.29, p<.001, partial η^2=.47-polishing system materially affects gloss level.
- **Composite type (A):** Not significant on its own, F (1.84)=3.02, p=.086, partial η^2=.035.
- **Polishing×thermal cycling (B×C):** Significant, F (2,84)=38.39, p<.001 - the magnitude of gloss loss from thermal cycling differs by polishing system.
- **Composite×thermal cycling (A×C):** Significant, F (1.84)=12.12, p<.001-the two composites lose gloss differently across thermal cycling.
- **Composite×polishing×thermal cycling (A×B×C):** Significant, F (2.84)=4.53, p=.014 - the polishing×thermal-cycling pattern itself differs somewhat between the two composites.
- **Composite×polishing (A×B):** Not significant, F (2.84)=0.44, p=.643.

Post-hoc comparisons: Thermal cycling effect within each composite×polishing group (**Table 4**).

Table 3. Three-way split-plot ANOVA results [composite (A)× polishing (B)× thermal cycling (C)]

Source	SS	df	MS	F	p	partial η^2
Composite type (A)	382.2	1	382.23	3.02	.086	.035
Polishing system (B)	9435.9	2	4717.97	37.29	<.001	.470
A×B	112.4	2	56.22	0.44	.643	.010
Subjects w/in cells (between-SS error)	10627.4	84	126.52	—	—	—
Thermal cycling (C)	87467.9	1	87467.95	829.70	<.001	.908
A×C	1277.3	1	1277.33	12.12	<.001	.126
B×C	8094.1	2	4047.05	38.39	<.001	.478
A×B×C	955.5	2	477.77	4.53	.014	.097
Residual (within-Ss error)	8855.4	84	105.42	—	—	—

*Between-subjects effects (A, B, A×B) tested against the subjects-within-cells error term; within-subjects effects (C, A×C, B×C, A×B×C) tested against the residual (within-subjects) error term. ANOVA: Analysis of variance, SS: Sum of squares, df: Degrees of freedom, MS: Mean square, F: F-statistic, η^2: Eta squared, w/in: Within, Ss: Subjects

Table 4. Paired t-tests (before vs. after TC), Bonferroni-corrected α=.05/6=.0083						
Composite	**Polishing system**	**Before TC**	**After TC**	**t(14)**	**p**	**Cohen's d**
VOCO	Twist Dia	69.45±11.32	19.27±7.75	14.03	<.001*	3.62
VOCO	Sof-Lex	66.32±14.43	27.03±7.37	8.98	<.001*	2.32
VOCO	Control	45.33±9.99	18.52±4.44	9.70	<.001*	2.50
Z250	Twist Dia	81.04±15.93	16.21±4.41	16.41	<.001*	4.24
Z250	Sof-Lex	79.80±18.91	21.11±5.34	12.48	<.001*	3.22
Z250	Control	44.99±10.86	20.26±6.64	9.34	<.001*	2.41

*Significant after Bonferroni correction. Effect sizes are very large (d=2.3-4.2) in every group-thermal cycling produced a substantial, statistically robust loss of gloss regardless of composite or polishing system. TC: Thermal cycling

Polishing system comparisons, pooled across composite: Before thermal cycling: one-way ANOVA F (2.87)=39.30, p<.001. Twist Dia and Sof-Lex produced statistically indistinguishable, high gloss; both were far glossier than the unpolished control (**Table 5**).

Table 5. Pairwise comparisons between groups using bonferroni correction			
Comparison	**Mean difference**	**t**	**p (Bonferroni)**
Twist Dia vs Sof-Lex	2.18	0.52	1.000 (ns)
Twist Dia vs control	30.08	9.15	<.001*
Sof-Lex vs control	27.90	7.41	<.001*

*Significant after Bonferroni correction. vs: Versus, ns: Not significant

After thermal cycling: One-way ANOVA F (2.87)=8.01, p<.001. The ranking changes-Sof-Lex retains significantly more gloss than either Twist Dia or the control after cycling, while Twist Dia and the control become statistically indistinguishable (**Table 6**).

Table 6. Bonferroni-adjusted pairwise comparisons of mean values between the Twist Dia, Sof-Lex, and control groups			
Comparison	**Mean difference**	**t**	**p (Bonferroni)**
Twist Dia vs Sof-Lex	-6.33	-3.66	.002*
Twist Dia vs control	-1.65	-1.06	.876 (ns)
Sof-Lex vs control	4.68	2.86	.018*

*Significant after Bonferroni correction. vs: Versus, ns: Not significant

Composite comparison, pooled across polishing system: Before TC: Z250 trended higher than VOCO (68.6 vs 60.4 GU), t (88)=-1.99, p=.050 (borderline). After TC: VOCO trended higher than Z250 (21.6 vs 19.2 GU), t (88)=1.69, p=.095 (n.s.). Neither simple effect reaches significance on its own, but the reversal in direction is consistent with the significant composite×thermal-cycling interaction reported above-Z250 starts glossier but loses relatively more gloss, ending on par with (or slightly below) VOCO.

DISCUSSION

In direct restorative dentistry, achieving an aesthetically pleasing result depends not only on color match and anatomical contouring but also on the initial surface gloss and its long-term retention.[1] Surface gloss directly influences light reflection and visual smoothness, which are critical parameters for the aesthetic success and lifespan of resin composite restorations.[1-3] The present study evaluated the immediate polishing effectiveness of a two-step diamond-impregnated spiral system (Twist Dia) and a four-step aluminum oxide disc system (Sof-Lex Disc) on a microhybrid (Filtek Z250) and a nanohybrid (GrandioSO) composite, as well as the stability of the achieved gloss following 15,000 thermal cycles. Based on the findings, the first null hypothesis (that the polishing system would not affect surface gloss) was not rejected for the immediate post-polishing stage but was rejected following thermal aging. The second null hypothesis (that composite type would not affect gloss) was not rejected: the main effect of composite type did not reach statistical significance in the split-plot ANOVA [F (1.84)=3.02, p=.086], although a non-significant trend toward higher gloss in Z250 was observed before thermal cycling (p=.050). The third null hypothesis (that thermal aging would not alter gloss) was rejected across all experimental groups.[9,14]

Immediately after polishing, both polishing systems provided a statistically significant increase in surface gloss compared with baseline values (all p<.001). However, no statistically significant difference in surface gloss was observed between Twist Dia and Sof-Lex Disc immediately after polishing (p=1.000, Bonferroni-corrected). This indicates that the two-step diamond-impregnated spiral system performed comparably to the multi-step aluminum oxide disc system in establishing initial surface gloss. Flexible aluminum oxide disc systems are widely used multi-step systems for achieving high surface smoothness and gloss due to their ability to sequentially reduce surface irregularities.[1,3] However, multi-step systems are time-consuming and can be challenging to apply on complex occlusal topographies. Diamond-impregnated elastomeric spiral systems allow flexible adaptation to irregular contours while combining finishing and polishing into fewer steps.[3,4] Our findings suggest that Twist Dia can achieve an initial surface gloss equivalent to Sof-Lex Disc, offering a clinically efficient alternative without compromising immediate aesthetic outcomes. Recent investigations by Ozaslan et al.[15] and Altınışık & Özyurt.[16] similarly demonstrated that multi-step disc systems and two-step diamond spiral polishing systems yield comparable initial surface smoothness, supporting the immediate efficacy of spiral polishing tools across various composite resin formulations.

Regarding the effect of composite formulation, Z250 showed a non-significant trend toward higher surface gloss than GrandioSO immediately after polishing (p=.050), and composite type did not reach significance as a main effect across the full model [F (1.84)=3.02,p=.086]. Although this trend did not reach conventional statistical significance, filler characteristics and matrix compositions may still explain the directional difference observed. Surface quality and gloss after polishing are strongly influenced by filler characteristics, such as filler size, morphology, loading, and the hardness contrast between inorganic fillers and the organic resin matrix.[3,4] GrandioSO is classified as a nanohybrid composite

with a higher total filler loading (89 wt%) containing glass ceramic particles (~1 μ"m") alongside functionalized silicon dioxide nanoparticles (20-40 nm). In contrast, Filtek Z250 is a microhybrid composite containing zirconia/silica particles (0.01-3.5 μ"m") embedded in a Bis-GMA/UDMA/Bis-EMA/TEGDMA matrix. During polishing, softer resin matrix components wear faster than hard inorganic filler particles. When abrasive instruments strike larger or harder filler agglomerates, protruding particles or micro-voids left by debonded fillers can increase diffuse light scattering, thereby reducing specular gloss. Furthermore, both polishing systems were applied under dry conditions without water cooling, as recommended by manufacturers for optimum visibility during finishing. However, dry polishing can generate localized frictional heat at the composite surface, potentially inducing micro-thermal degradation or plastic deformation of the organic matrix, particularly in composites with higher resin matrix ratios or specific monomer blends. The lower initial gloss trend observed in GrandioSO may be attributed to the selective wear and thermal friction around its larger glass ceramic filler particles, whereas the zirconia/silica filler distribution in Filtek Z250 allowed more uniform surface abradability under the applied polishing protocols. This material-dependent polishing response aligns with the findings of Lippert et al.,[17] who emphasized that the physical structure and filler composition of the resin composite dictate the maximum achievable gloss recovery after surface treatment.

Thermal aging represents a critical challenge to the intraoral stability of resin composite restorations. In the current study, all experimental groups experienced a marked and statistically significant reduction in surface gloss following 15,000 thermal cycles ($p<0.001$), with large effect sizes (Cohen's d ranging from 2.32 to 4.24). Repeated thermal stress between 5°C and 55°C induces alternating expansion and contraction cycles between the organic matrix and inorganic fillers, which have mismatching coefficients of thermal expansion. This mismatched thermal movement generates micro-shear stresses at the matrix-filler interface, promoting microcracking, filler debonding, and hydrolytic degradation. Furthermore, water sorption during thermal cycling leads to plasticization and swelling of the resin matrix. These microstructural alterations create nanoscale surface irregularities that impair specular light reflection, leading to a substantial drop in surface gloss across all groups.[9,14]

To contextualize these findings, it is useful to consider previously reported visual thresholds for surface gloss. da Costa et al.[18] reported visually acceptable gloss thresholds for resin composites in the range of approximately 40-50 GU. Both Twist Dia and Sof-Lex Disc achieved immediate post-polishing gloss values above this range (66.32±14.43 GU to 81.04±15.93 GU), whereas post-aging values across the experimental groups decreased to 16.21±4.41 GU to 27.03±7.37 GU. Although these laboratory values fall below the reported visual acceptability range, they should not be interpreted as demonstrating clinical unacceptability directly. Thermocycling is an accelerated artificial-aging procedure and does not reproduce the full complexity, duration, or combined mechanical, chemical, and biological challenges of clinical service. Therefore, the post-aging findings indicate a substantial reduction in gloss under the present experimental conditions rather than a direct prediction of clinical aesthetic failure.

Interestingly, while the choice of polishing system did not significantly influence gloss immediately after polishing, a significant difference emerged between polishing systems after thermal aging [$F(2.87)=8.01$, $p<.001$ overall; Sof-Lex vs. Twist Dia, $p=.002$, Bonferroni-corrected]. Specifically, specimens polished with the Sof-Lex Disc system retained higher gloss values than those polished with Twist Dia after 15,000 thermal cycles. Multi-step aluminum oxide discs, such as Sof-Lex, use sequentially finer abrasives (55 μm to 8 μm), which may contribute to differences in the surface produced by the polishing procedure. One possible explanation for the different post-aging behavior is that the two polishing protocols generated surfaces with different topographical characteristics that subsequently responded differently to thermal stress. However, surface roughness and morphology were not directly assessed in the present study; therefore, mechanisms involving microscopic grooves, subsurface stresses, filler exposure, or interfacial degradation remain hypothetical and cannot be confirmed from the current data. The present findings support only the conclusion that Sof-Lex showed greater gloss retention than Twist Dia under the applied thermocycling conditions. Ozaslan et al.[15] likewise reported polishing-system-dependent differences after artificial aging, although direct mechanistic comparisons should be made cautiously because of differences in materials and outcome measures.

It is important to note that while artificial aging protocols provide valuable insight into material durability, 15,000 thermal cycles represent an accelerated environmental challenge rather than a direct mathematical equivalent of clinical exposure. Although 10,000 cycles are frequently cited as approximating one year of clinical service, laboratory thermal cycling lacks complex intraoral dynamics such as mechanical wear, tooth brushing, saliva buffering, bio-abrasion, and dietary chemical exposure.[9,14] Therefore, the findings of this study should be interpreted as a comparative evaluation of composite formulation and polishing system resistance under thermal stress, rather than an exact prediction of clinical longevity.

Limitations

Although this study provides valuable insights into the immediate efficacy and thermal stability of different composite polishing systems, several inherent limitations associated with the in vitro design should be acknowledged:

- **Absence of complex intraoral dynamics:** The thermal cycling protocol (15,000 cycles) simulated temperature fluctuations but did not incorporate other critical intraoral aging factors, such as mechanical wear from tooth brushing, bio-abrasion, salivary buffering and enzymatic action, cyclic fatigue loading, or exposure to dietary chemical challenges.
- **In vitro polishing standardization:** All polishing procedures were performed by a single experienced operator using standardized rotational speeds, sequences, and application times; however, polishing pressure was applied manually and was not instrumentally quantified or standardized. Consequently, small variations in applied force may have influenced the resulting gloss values. This limitation should be considered when interpreting differences between polishing systems and when extrapolating the findings to clinical practice.

- **Limited range of materials and systems:** Only two composite resin formulations (a microhybrid and a nanohybrid) and two polishing protocols (a two-step spiral and a four-step disc system) were investigated. Therefore, these results may not be directly extrapolated to other composite categories (such as bulk-fill, flowable, or single-shade resin composites) or alternative polishing technologies (such as one-step systems or diamond polishing pastes).
- **Single-parameter evaluation:** Surface gloss was evaluated as the primary outcome parameter. Surface roughness and morphology were not directly assessed; therefore, proposed mechanisms involving microscopic grooves, subsurface stresses, filler exposure, or other topographical changes cannot be confirmed by the present data. Incorporating surface roughness profiling, scanning electron microscopy (SEM), or atomic force microscopy (AFM) in future studies would provide a more comprehensive understanding of the surface changes occurring before and after thermal aging.

CONCLUSION

Within the limitations of this in vitro study, the following conclusions can be drawn:

- **Efficacy of polishing systems:** Immediately after polishing, the two-step diamond-impregnated spiral system (Twist Dia) achieved surface gloss values comparable to those obtained with the traditional four-step aluminum oxide disc system (Sof-Lex Disc). This indicates that two-step elastomeric spiral systems offer a clinically efficient and effective alternative for initial gloss generation without requiring multi-step disc protocols.
- **Influence of composite formulation:** Composite type did not significantly affect overall surface gloss [$F(1.84)=3.02$, $p=.086$]; however, a non-significant trend toward higher initial gloss was observed in Filtek Z250 compared with GrandioSO ($p=.050$), and the significant composite type×thermal cycling interaction ($p<.001$) indicates that the two composites lost gloss differently over the course of thermal aging.
- **Impact of thermal aging:** Thermal aging (15,000 thermal cycles) caused a marked and statistically significant reduction in surface gloss across all evaluated composite resins and polishing systems, demonstrating the susceptibility of polished composite surfaces to thermal-induced degradation and microstructural stress.
- **Long-term gloss retention:** Although initial gloss levels were equivalent between the polishing systems, the Sof-Lex Disc system demonstrated superior resistance to thermal aging compared to Twist Dia, retaining significantly higher gloss values after 15,000 thermal cycles. Sequential aluminum oxide disc polishing appears to provide better long-term gloss stability under thermal stress.

ETHICAL DECLARATIONS

Ethics Committee Approval

Ethics committee approval was not required because this was an in vitro laboratory study conducted exclusively using commercially available resin composite materials, without involving human participants, human-derived biological specimens, or animals.

Informed Consent

Informed consent was not required because this in vitro laboratory study did not involve human participants or human-derived biological materials.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The author declares no conflicts of interest related to this study.

Financial Disclosure

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Author Contributions

The author is solely responsible for the entirety of conception, execution, analysis, and writing of the manuscript.

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Is the surface abrasiveness of the dental stain eraser on composite resin as minimal as that of the rubber-cup?

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ABSTRACT

Aims: The aim of this study is to compare the abrasive effect of dental stain erasers on dental resin composites with the rubber cup and prophylaxis paste, which are routine methods used to remove stains in professional practice.

Methods: Composite resin blocks were prepared and initial surface roughness measurements were made. Application areas were divided into equal areas in each block and marker was used to color equal surface areas of each section (5x5 mm). The stain removal methods to be compared were applied to the divided surfaces (n=9), and roughness values were measured again.

Results: It was observed that the dental stain eraser (SE) group created significantly more roughness on the composite surfaces (0.312815) compared to the rubber cup (RC) group (0.213556) ($p<0.001$). Additionally, the roughness values of the SE and RC groups were significantly higher than those of the control group ($p<0.001$).

Conclusion: Compared to application with rubber cup and prophylaxis paste, dental stain eraser is more abrasive on composite resin surfaces.

Keywords: Polishing, dental stain, abrasion, dental stain eraser

INTRODUCTION

Tooth color is one of the most important characteristics related to the aesthetics of the dental arch.[1] Extrinsic tooth discoloration occurs when chromogenic substances accumulate in the pellicle, plaque, or calcified attachments on the tooth surface.[2] External discoloration, which can be in various colors such as brown, yellow and black, can cause aesthetic discomfort.[3]

The aim of periodontal treatment is to obtain healthy periodontal tissues by eliminating local etiological factors such as bacterial deposits and tartar from the tooth surface.[4] Polishing can be considered the final stage of periodontal treatment.[5]

Although enamel and cementum may present a clinically smooth surface after debridement to the unaided eye, they present various surface irregularities that can be detected microscopically. A smooth enamel or cementum is less likely to accumulate plaque and this can only be achieved by polishing after scaling or root debridement.[6] Studies have shown that polishing removes microbial dental plaque, reduces bacterial accumulation, smoothes the tooth surface after scaling, and removes stains.[7-9] In contemporary dentistry, polishing is done with manual and motorized devices such as a porte polisher, polishing strips, a rubber/prophylaxis cup, a bristle/prophylaxis brush, an air polisher, and a vector system with various prophylactic pastes/powders. Among the various polishing methods available, rubber cup with pumice/polishing paste is the most common.[10] Teeth polishing may seem easy, simple and even mundane, but it involves many interconnected and complex issues and can cause unnecessary harm if not done properly.[11] Dentists have made efforts to correct the tooth surface with minimal damage through many studies.[12]

Nowadays, products called 'dental stain eraser', which can be easily found in the markets, are offered for sale so that people can remove stains on their teeth at home without having to make a dentist appointment. With this material, people aim to provide the aesthetics of their teeth themselves. However, there are no studies investigating the effects of these commonly used products on tooth surface tissue.

Composite resin materials are designed to match the tooth structure. However, they stain more than enamel.[13] In our study, dental composite resin blocks were used to take advantage of their color retention properties; and the aim was to compare the abrasive effect of the rubber cup (with polishing paste), which is the most preferred in clinical applications, and the dental stain eraser after removing the stain on the dental composite surface with profilometer measurements.

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The null hypothesis of this study is that there is no difference between the dental stain eraser and the rubber cup in creating roughness on the surface structure of the stain removal process.

METHODS

Ethics

The present study was designed as an in vitro laboratory investigation and was conducted exclusively on restorative material specimens. The study did not involve human participants, identifiable or private human data, human biological samples, or live animals. No clinical intervention, treatment, or data collection from patients was performed. Accordingly, the study did not constitute human-subject or animal research requiring review and approval by an institutional ethics committee under the applicable institutional framework. Therefore, ethical committee approval was not obtained for this study. All procedures were carried out in accordance with the ethical rules and the principles.

Study Design

The sample size was calculated using the software program (G*Power version 3.0.8, Heinrich Heine University, Düsseldorf) with data from a study[14] evaluating the abrasiveness of various material treatments of composite surfaces. With an effect size of 3.16, 95% power, and α=0.05, the minimum number of samples required for this investigation was 4 per group.

Specimen Preparation

Dental composite material (3M Filtek Z250) was applied in block form. To ensure standardization, a Mylar matrix strip was placed on the block surface, and then the matrix was covered using a flat glass plate. A 1 kg stainless steel weight was applied to the sample for 30 seconds and the composite was allowed to flow and obtain a smoother, standard surface. The polymerization tip was applied directly to the Mylar matrix strip and the samples were light cured according to the manufacturer's instructions (Demetron Optilux 501e).

In order to create equal amounts of coloration on the application surface of the two materials compared, a single composite block was prepared with celluloid tape to form 6 equal sections and a total of 18 sections were separated for each group (n=9). The surface of the samples was considered as two separate planes, right and left; the right side was determined as the SE surface and the left side as the RC surface. It was aimed to imitate dental stain by painting each separated section with 'permanent marker' by making use of its usage in the literature,[15] (ED47277, Edding®, Wunstorf, Germany) as 5x5 mm.

Stain Removal Procedures

On the polishing areas, polishing paste (Detartrine, Septodont®, Saint-Maur, France) and rubber-cup (EPY003A, Stoddard®, Letchworth, UK) were used at 2500 rpm with light pressure (to make the edges flare slightly).

On the erasing areas, dental stain eraser (Pakdent®, Bolu, Turkiye) was moved back and forth on the surface until the discoloration was observed to be removed, with the tip of the eraser applied with light pressure as recommended by the manufacturer.

All stain removal procedures were performed by a single periodontist, and then the remaining residues on the block were cleaned by rinsing with physiological saline.

Profilometrical Analysis

Surface roughness was investigated by profilometric analysis. For this purpose, Bruker Dektak XT profilometer was used. The roughness of each sample was determined by considering the data obtained at 100 µm intervals along 1 mm measurement profiles. The obtained profile data were corrected by polynomial curve fitting method in order to eliminate the curvilinear deviation of the sample during the process.

Statistical Analysis

All data analyses were performed with a software program (SPSS v.20.0; IBM, Chicago, IL, USA). Parameter comparisons were made using the ANOVA test. Dunn test (with Bonferroni correction) was used for multiple comparisons of surface roughness parameters.

RESULTS

Table shows the average surface roughness average (Ra) value and standard deviation of the experimental groups.

Table. Surface roughness average values of the groups

Groups	Ra (mean+SD)
Control	0.045778+0.01294
Rubber cup	0.213556+0.1080661[a]
Stain eraser	0.312815+0.2885772[ab]

a: significant difference compared to control group (p<0.005). b: significant difference compared to rubber cup group (p<0.001). Ra: Roughness average, SD: Standard deviation

As a result of the profilometric analyses, the average Ra value of the control group was recorded as 0.045778, while the RC group was 0.213556 and the SE group was 0.312815. According to the Bonferonni analysis in which we examined the difference between the groups, it was seen that the RC group showed a significant difference in surface roughness compared to the control group (p<0.005), and the SE group showed a significant difference in surface roughness compared to the control group (p<0.001).

When the analyses between the groups were examined, it was observed that the SE group showed significantly more roughness compared to the RC group (p<0.001).

Figure shows the surface roughness values of the groups graphically.

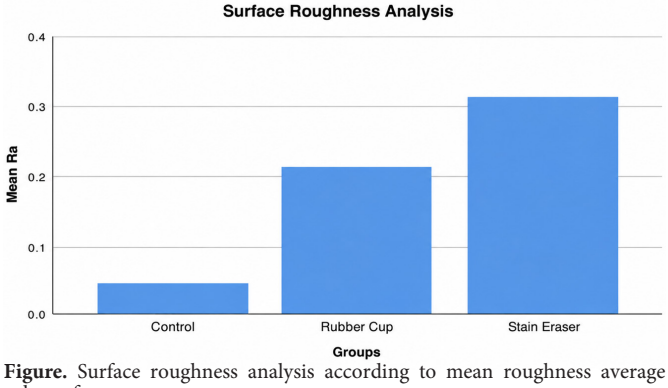

Figure. Surface roughness analysis according to mean roughness average values of groups

Ra: Roughness average

DISCUSSION

Facial attractiveness and smile are closely linked. Especially in the front teeth, tooth color is an important element of smile aesthetics and therefore self-confidence.[16] As the severity of tooth discoloration increases, a person's sense of self-esteem decreases.[17]

However, since dentist appointments create stress and financial cost problems for patients,[18] it is understandable that they tend to turn to products that they can apply at home. No research has been observed in the literature assessing the effects of this commonly preferred product. Therefore, our study aimed to evaluate the amount of abrasion that the use of an over-the-counter product, 'dental stain eraser', will create on the tooth tissue during the stain removal process in the comfort of people's homes, by comparing it with professional application.

Manual dexterity is an important skill in mastering dentistry, and it is essential for dentistry students and clinicians to acquire the ability and skill to perform dental procedures. Practical experience of tactile knowledge is needed to gain clinical expertise.[19]

Tactile sensitivity allows people to extract information about objects and make decisions based on their perceived features.[20-22] Education level is one of the factors that increases the touch sensitivity of health sciences students.[23] It has been shown that professional dental stain cleaning can cause damage to the tooth enamel, depending on factors such as application time and pressure, including manual dexterity, by clinicians who will be more sensitive to dental tissues than other individuals.[24]

There is no professional involvement in the applications of 'over-the-counter products'.[25] Individuals who are not trained and have no practical experience will have insufficient touch sensitivity and will be more likely to cause harmful applications to dental tissues. However, the tooth surface should be corrected with minimum damage.[12] In order to ensure optimization in our study, both products compared were applied by a periodontist.

After tartar cleaning, polishing is usually applied to remove discoloration and residues on the tooth. Discolorations that can be removed by polishing are of the external tooth coloration type and occur on the outer surface.[26]

Different polishing techniques are preferred in dental clinics today. The most commonly used ones are polishing with a rubber cup or brush. These techniques are performed by applying an abrasive polishing paste with the help of a rotary tool.[24]

The reason for choosing a rubber cup in our study is that polishing with a rubber cup has been shown to be the most effective method in obtaining a smooth tooth surface and removing residues from enamel and cementum, compared to polishing with a bristle brush or air polisher.[7]

Generally, dental rotating systems and their associated products generate heat due to frictional forces.[27,28] Ertugrul and Orhan[29] reported that rubber cups used with prophylaxis paste resulted in relatively low intrapulpal temperature increases, whereas those used without paste frequently exceeded the critical temperature rise threshold of 5.6°C. For this reason, since the standard application would be with paste, in our study, a rubber cup application was also made together with the paste.

Commercially available prophylaxis polishing pastes usually combine abrasives with a binder, moisturizers, a coloring agent, a preservative, and a sweetener.[30] It creates minimum scratches and provides a highly reflective surface.[31] The polishing process to remove discoloration, including factors such as the abrasiveness of the paste used, the rotation speed of the rotary tool, the application pressure, and the application time, affects the increasing temperature and the roughness that occurs on the surface.[24] Studies have reported that the average speed that should be used is 2500 rpm.[10,24] In this context, we preferred to apply rubber cup and paste at 2500 rpm.

The content of the dental stain eraser product is polypropylene (PP), thermoplastic rubber (TPR), and carborundum (silicon carbide). Carborundum is used in discs and stones in dentistry practice; it functions as a grinding material in cutting and thinning the teeth.[32]

Limitations

In our study, markers were used to mimic the stain to be removed. However, the fact that the homogeneity of the staining areas was visually controlled is one of the limitations of our study.

In our study, it was revealed that dental stain eraser caused more abrasion on the surface compared to the process performed with rubber-cup and paste, which is one of the professional routine applications for stain removal. It is possible that the carborundum content is a factor in this situation.

In our study, dental composite resin blocks were used to evaluate abrasiveness; however, further research on tooth surfaces is needed for a more comprehensive evaluation of the abrasive effect. Furthermore, the application pressure was not quantitatively calibrated, which may have introduced variability in the surface roughness measurements.

CONCLUSION

Removing the discolorations with a stain eraser caused more scratches on the composite resin surface compared to professional applications. It is more reliable to prefer professional applications in stain removal for Using stain removers to remove discoloration has resulted in more scratches on the composite resin surface compared to professional applications. Professional stain removal methods are more reliable for composite surfaces.

Clinical Relevance

- **Scientific rationale:** Although the use of over-the-counter dental products is attractive to the public, whether or not their use is safe for dental tissues is vital. Our study compared dental stain eraser abrasiveness to rubber-cup and paste, which are among the professional applications.
- **Principal findings:** Profilometric measurements showed that dental stain eraser created significantly higher roughness on the composite surface compared to rubber-cup in removing equal amounts of stain ($p<0.005$).
- **Practical implications:** Dental stain eraser showed higher abrasiveness compared to the professional application. While more research is required, steps can be taken to ensure that individuals are informed about the impacts of easily purchased dental products.

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

Since the study was conducted without the participation of any living being, no written consent form was obtained.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

Financial Disclosure

The authors received no financial support for the conduct or publication of this research.

Author Contributions

Design: EÖ, LS; Data Collection and/or Processing: EÖ, AE; Analysis and/or Interpretation: LS; Writing the Article: EÖ.

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Original Article

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Evaluation of prosthetic restorations in patients receiving dental implants according to patient demographics and treatment variables

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ABSTRACT

Aims: Patients receiving dental implant treatment may undergo rehabilitation with both implant-supported and conventional prosthetic restorations. Evaluating the distribution of these restorations according to demographic characteristics and implant number may help characterize prosthetic treatment patterns in clinical practice. This retrospective cross-sectional study aimed to evaluate the types and counts of prosthetic restorations provided to patients who completed prosthetic rehabilitation following dental implant treatment at a university clinic between 2023 and 2024 and to examine their associations with age, gender, and implant number.

Methods: This retrospective cross-sectional study analyzed the digital records of 514 adult patients who completed prosthetic rehabilitation following dental implant treatment at a university clinic between 2023 and 2024. Age, gender, implant number, and prosthetic restoration types and counts were recorded. Restorations included implant-supported crowns, implant-supported overdentures, tooth-supported metal-ceramic crowns, conventional complete dentures, and conventional removable partial dentures. Differences across age groups and between genders were assessed using the Kruskal-Wallis and Mann-Whitney U tests, respectively. Post hoc pairwise comparisons were performed using Dunn's test with Bonferroni adjustment. Associations between variables were evaluated using Spearman's rank correlation analysis and simple linear regression. Statistical significance was set at $p<0.05$.

Results: The study included 514 patients with a mean age of 51.18±13.50 years. Significant differences across age groups were observed in implant number and counts of all evaluated prosthetic restoration types ($p<0.05$). Young adults had fewer implants, whereas the middle-aged group had higher counts of implant-supported crowns and tooth-supported metal-ceramic crowns. Implant-supported overdentures and conventional complete dentures had higher counts in the elderly group. A strong positive correlation was observed between implant number and implant-supported crown count ($\rho=0.791$, $p<0.001$), and a moderate positive correlation was found between age and implant-supported overdenture count ($\rho=0.409$, $p<0.001$). Males were significantly older than females ($p=0.003$), whereas implant and prosthetic restoration counts did not differ significantly between genders ($p>0.05$).

Conclusion: The distribution of prosthetic restorations among patients receiving dental implants differed significantly across age groups. These findings indicate an association between age and prosthetic treatment patterns and may inform treatment planning in conjunction with individual clinical needs.

Keywords: Dental implants, prosthetic rehabilitation, implant-supported prostheses, overdentures, age distribution

INTRODUCTION

Dental implants are widely used to replace missing teeth because of their high survival rates and predictable long-term clinical outcomes.[1,2] Implant-supported single crowns and fixed dental prostheses are established options for the rehabilitation of single-tooth loss and partial edentulism.[3]

In patients with complete edentulism of the maxilla, fixed full-arch prostheses and implant-supported overdentures provide alternative approaches to prosthetic rehabilitation.[4] Implant-supported fixed prostheses provide a reliable option for prosthetic rehabilitation, with high survival rates reported in clinical studies.[5,6] Nevertheless, biological and technical complications may occur over time, highlighting the importance of prosthetic design and maintenance.[6,7] For completely edentulous patients, implant-supported overdentures offer a removable treatment option that can improve prosthesis stability, oral function, and patient satisfaction compared with conventional complete dentures.[8] For patients with complete mandibular edentulism, overdentures retained by two implants placed in the anterior mandible have been recommended as the first-choice standard of care by the York and McGill consensus statements.[8,9]

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Long-term clinical evidence also supports this approach, with a 10-year clinical trial reporting favorable outcomes for mandibular two-implant overdentures.[10]

Although the clinical outcomes and complication rates of implant-supported single crowns and fixed dental prostheses have been extensively investigated,[3,5-7] these outcomes do not fully describe the distribution of prosthetic restorations provided to patients receiving dental implants in routine clinical practice. Evaluating both implant-supported and conventional restorations within this patient population may provide a broader understanding of prosthetic rehabilitation patterns in university clinics. Examining their distribution according to age, gender, and the number of implants may help characterize differences in treatment provision and provide information relevant to clinical planning.

Therefore, this retrospective cross-sectional study aimed to evaluate the types and counts of prosthetic restorations provided to adult patients who completed prosthetic rehabilitation following dental implant treatment at a university clinic between 2023 and 2024. Specifically, the study examined differences in implant number and prosthetic restoration counts across age groups and between genders, as well as associations among age, implant number, and prosthetic restoration counts. The null hypotheses were that implant number and prosthetic restoration counts would not differ significantly across age groups or between genders and that no significant correlations would exist among age, implant number, and prosthetic restoration counts.

METHODS

Ethics

Ethical approval was obtained from the İnönü University Health Sciences Scientific Researches Ethics Committee (Date: 24.02.2026, Decision No: 2026/9438). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki.

Study Design

This retrospective cross-sectional study was conducted by reviewing the digital records of patients who completed prosthetic rehabilitation following dental implant treatment at the Department of Prosthodontics, Faculty of Dentistry, İnönü University, between 2023 and 2024. The study evaluated both implant-supported and conventional prosthetic restorations provided to these patients.

Study Population

The study population comprised adult patients aged 18 years or older who completed prosthetic rehabilitation following dental implant treatment during the specified study period. A total of 514 patients meeting the inclusion criteria were included in the analysis.

Inclusion and Exclusion Criteria

Patients were eligible for inclusion if they were aged 18 years or older, received dental implant treatment between 2023 and 2024, and completed prosthetic rehabilitation. Patients with incomplete digital records or unfinished prosthetic treatment were excluded.

Data Collection and Variables

Data were retrospectively extracted from the digital patient record system. Demographic variables included age and gender. Treatment-related variables included implant number and the types and counts of prosthetic restorations provided to each patient. Both implant-supported and conventional restorations were evaluated using the following categories:

- **Implant-supported crowns:** Single-unit crowns and individual units of implant-supported fixed bridges. Each bridge unit was counted separately rather than counting the entire bridge as one restoration.
- **Implant-supported overdentures:** Removable overdentures supported by dental implants.
- **Tooth-supported metal-ceramic crowns:** Conventional metal-ceramic restorations supported by natural teeth.
- **Conventional complete dentures:** Complete dentures without implant support.
- **Conventional removable partial dentures:** Removable partial dentures without implant support.

For age-group comparisons, patients were categorized as young adults (18-44 years), middle-aged adults (45-59 years), and older adults (≥60 years). These study-specific categories were used to describe and compare prosthetic treatment patterns across adult age groups.

Statistical Analysis

All data analyses were performed using IBM SPSS Statistics, version 27 (IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Shapiro-Wilk test. Descriptive statistics were presented as mean (standard deviation) and median [interquartile range (IQR)] to provide a comprehensive summary of the distributions, particularly for count variables with skewed distributions and a high proportion of zero values. Categorical variables were expressed as frequencies (n) and percentages (%). Means with standard errors (SE) were also presented for age-group and gender comparisons.

The Kruskal-Wallis test was used to compare the numbers of implants and prosthetic restorations across age groups. When statistically significant differences were identified, post-hoc pairwise comparisons were performed using the Dunn-Bonferroni procedure, with Bonferroni adjustment for multiple comparisons. The Mann-Whitney U test was used to compare age, implant number, and prosthetic restoration numbers between genders. Associations among age, implant number, and prosthetic restoration variables were assessed using Spearman's rank correlation coefficient (ρ). Simple linear regression analyses were performed to examine the relationships between selected variables. Four separate models were constructed: (1) age as the dependent variable and implant-supported overdenture count as the independent variable; (2) implant number as the dependent variable and implant-supported crown count as the independent variable; (3) implant-supported overdenture count as the dependent variable and implant-supported crown count as the independent variable; and (4) implant-supported overdenture count as the dependent variable and conventional complete denture count as the independent variable. Regression results were reported using unstandardized regression coefficients (B), SE, standardized regression coefficients (β), 95% confidence intervals for B, and coefficients of determination

(R^2). All tests were two-sided, and statistical significance was set at $p<0.05$.

RESULTS

A total of 514 patients were included in the study (**Table 1**). The middle-aged group accounted for the largest proportion of patients (40%), whereas the elderly group accounted for the smallest proportion (29.37%) (**Table 2**).

Table 1. Descriptive statistics of patient age, implant number, and prosthetic restoration counts

Variable	n	Median (IQR)	Mean (SD)
Age (years)	514	52(19)	51.18 (13.50)
Number of implants	514	3(3)	3.92 (3.11)
Implant-supported crowns	514	3(6)	5.03 (6.07)
Implant-supported overdentures	514	0 (0)	0.19 (0.43)
Tooth supported metal-ceramic crowns	514	0 (4)	2.76 (4.64)
Conventional complete dentures	514	0 (0)	0.12 (0.33)
Conventional removable partial dentures	514	0 (0)	0.02 (0.15)

Data are presented as median (IQR) and mean (SD). IQR: Interquartile range, SD: Standard deviation

The number of tooth-supported metal-ceramic crowns differed significantly across age groups. The middle-aged group had a significantly higher mean count than the other two groups ($p<0.05$) (**Table 2**).

The number of conventional complete dentures differed significantly across age groups. All three groups differed significantly from one another ($p<0.05$), with the lowest mean count in young adults and the highest in the elderly group (**Table 2**).

The number of conventional removable partial dentures differed significantly across age groups. Young adults had a significantly lower mean count than elderly patients ($p<0.05$) (**Table 2**).

Age differed significantly between genders, with males being older than females ($Z=2.95$; $p=0.003$; $r=0.13$). No significant differences were observed between genders in the numbers of implants or prosthetic restorations ($p>0.05$) (**Table 3**).

Correlation analysis revealed a moderate positive association between age and the number of implant-supported overdentures ($p<0.001$) (**Table 4**).

Table 2. Comparison of implant and prosthetic restorations according to age groups

	Age groups	n	Mean (SE)	Kruskal-Wallis H	p-value	η^2
Number of implants	Young adult	155	2.66 (0.17) A	52.67	<0.001	0.09
	Middle-aged	208	4.46 (0.23) B			
	Elderly	151	4.48 (0.27) B			
Implant-supported crowns	Young adult	155	3.36 (0.29) B	17.53	<0.001	0.03
	Middle-aged	208	5.98 (0.44) A			
	Elderly	151	5.42 (0.58) B			
Implant-supported overdentures	Young adult	155	0.01 (0.01) A	90.51	<0.001	0.17
	Middle-aged	208	0.13 (0.03) B			
	Elderly	151	0.45 (0.05) C			
Tooth supported metal-ceramic crowns	Young adult	155	1.58 (0.30) A	19.10	<0.001	0.03
	Middle-aged	208	3.68 (0.35) B			
	Elderly	151	2.72 (0.37) A			
Conventional complete dentures	Young adult	155	0.01 (0.01) A	56.82	<0.001	0.11
	Middle-aged	208	0.10 (0.02) B			
	Elderly	151	0.28 (0.04) C			
Conventional removable partial dentures	Young adult	155	0.01 (0.01) A	6.62	<0.05	0.01
	Middle-aged	208	0.01 (0.01) AB			
	Elderly	151	0.05 (0.02) B			

Different superscript letters (A, B, C, etc.) within the same variable indicate statistically significant differences between age groups based on Dunn-Bonferroni post-hoc pairwise comparisons following the Kruskal-Wallis test (adjusted $p<0.05$). SE: Standard error

The number of implants differed significantly across age groups. Post-hoc comparisons indicated significantly lower implant counts in young adults than in middle-aged and elderly patients (adjusted $p<0.001$) (**Table 2**).

The number of implant-supported crowns also differed significantly across age groups. Post-hoc comparisons identified significant differences between the middle-aged group and both other age groups (adjusted $p<0.05$) (**Table 2**).

Significant differences were observed in the number of implant-supported overdentures across age groups. All three groups differed significantly from one another ($p<0.05$), with the highest mean count in the elderly group and the lowest in the young adult group (**Table 2**).

A strong positive association was observed between the number of implants and implant-supported crowns ($\rho=0.791$, $p<0.001$) (**Table 4**).

A strong negative association was found between the numbers of implant-supported overdentures and implant-supported crowns ($p<0.001$) (**Table 4**).

In the linear regression model, implant-supported overdenture count explained 14.4% of the variance in age ($R^2=0.144$; $p<0.001$) (**Table 5**).

In the model with implant number as the dependent variable and implant-supported crown count as the independent

Table 3. Comparison of age, implant number and prosthetic restorations according to gender

	Gender	Patients treated, n (%)	Mean (SE)	p-value
Age (years)	Male	202 (100.0)	53.05 (1.00)[A]	0.003
	Female	312 (100.0)	49.96 (0.73)[B]	
Number of implants	Male	202 (100.0)	3.98 (0.24)	0.476
	Female	312 (100.0)	3.88 (0.17)	
Implant-supported crowns	Male	172 (85.1)	5.21 (0.46)	0.725
	Female	261 (83.7)	4.90 (0.33)	
Implant-supported overdentures	Male	32 (15.8)	0.18 (0.03)	0.584
	Female	56 (17.9)	0.19 (0.02)	
Tooth supported metal-ceramic crowns	Male	85 (42.1)	2.45 (0.31)	0.434
	Female	135 (43.3)	2.97 (0.27)	
Conventional complete dentures	Male	22 (10.9)	0.11 (0.02)	0.389
	Female	42 (13.5)	0.13 (0.02)	
Conventional removable partial dentures	Male	5 (2.5)	0.02 (0.01)	0.673
	Female	6 (1.9)	0.02 (0.01)	

Different superscript letters (A, B) indicate statistically significant differences between genders according to the Mann-Whitney U test ($p<0.05$). Percentages were calculated within each gender group. Mean counts and standard errors include patients with zero restorations. p-values refer to comparisons of age or implant and prosthetic restoration counts, rather than treatment proportions. SE: Standard error

Table 4. Correlation analyses between age and implant and prosthetic variables

Variable	Age (years)	Number of implants	Implant-supported crowns	Implant-supported overdentures	Tooth-supported metal-ceramic crowns	Conventional complete dentures	Conventional removable partial dentures
Age (years)	1.00	0.286**	0.028	0.409**	0.076	0.336**	0.114**
Number of implants	0.286**	1	0.791**	-0.069	0.283**	-0.162**	0.031
Implant-supported crowns	0.028	0.791**	1	-0.595**	0.360**	-0.525**	-0.035
Implant-supported overdentures	0.409**	-0.069	-0.595**	1	-0.246**	0.780**	0.178**
Tooth-supported metal-ceramic crowns	0.076	0.283**	0.360**	-0.246**	1	-0.298**	0.087*
Conventional complete dentures	0.336**	-0.162**	-0.525**	0.780**	-0.298**	1	-0.056
Conventional removable partial dentures	0.114**	0.031	-0.035	0.178**	0.087*	-0.056	1

Correlation coefficients are presented as Spearman's ρ. *$p<0.05$; **$p<0.01$ (two-tailed)

Table 5. Results of simple linear regression analyses

Model	Dependent variable	Independent variable	B	SE	β	95% CI	p-value	R^2
1	Age	Implant-supported overdenture count	11.790	1.271	0.379	9.292-14.287	<0.001	0.144
2	Number of implants	Implant-supported crowns	0.457	0.01	0.891	0.437-0.477	<0.001	0.794
3	Implant-supported overdenture count	Implant-supported crowns	-0.024	0.003	-0.332	-0.030-(-0.018)	<0.001	0.110
4	Implant-supported overdenture count	Conventional complete denture count	0.891	0.043	0.678	0.807-0.975	<0.001	0.460

In the linear regression model, implant-supported overdenture count explained 14.4% of the variance in age ($R^2=0.144$; $p<0.001$). B: Regression coefficient, SE: Standard error, β: Standardized coefficient, CI: Confidence interval

variable, the coefficient of determination was $R^2=0.794$ ($p<0.001$) (**Table 5**).

In the model with implant-supported overdenture count as the dependent variable and implant-supported crown count as the independent variable, the coefficient of determination was $R^2=0.11$ (**Table 5**).

In the model with implant-supported overdenture count as the dependent variable and conventional complete denture count as the independent variable, the coefficient of determination was $R^2=0.46$ ($p<0.001$) (**Table 5**).

DISCUSSION

This retrospective cross-sectional study evaluated the distribution of implant-supported and conventional prosthetic restorations in patients who completed rehabilitation following dental implant treatment between 2023 and 2024. Significant differences were observed across age groups in implant number and prosthetic restoration counts, whereas these variables did not differ significantly between genders. Associations were also identified among age, implant number, and several restoration types. Accordingly, the null hypotheses were partially rejected. These findings describe treatment patterns within the study population rather than patient preferences.

Young adults had significantly fewer implants than patients in the other age groups. This finding may reflect more localized tooth loss and less extensive rehabilitation needs in younger patients. However, the extent and distribution of edentulism

were not recorded, and this explanation therefore remains tentative. Implant-supported single crowns and fixed partial dental prostheses provide treatment options for single-tooth loss and partial edentulism.[3]

The strong positive correlation between implant number and implant-supported crown count indicates that patients with more implants generally received more fixed restoration units. Because the crown variable included single crowns and individual units of fixed bridges, this association should be interpreted in terms of restored units rather than as a one-to-one relationship between implants and crowns.

The middle-aged group had significantly higher numbers of implant-supported crowns and tooth-supported metal-ceramic crowns than the other groups. This pattern suggests that fixed rehabilitation involving both implants and natural teeth was more extensive in this age group. The condition of the remaining dentition, the distribution of edentulous spaces, and the suitability of available abutments may have contributed to these differences. Clinical studies have reported high survival rates for implant-supported fixed complete prostheses, although technical complications and maintenance requirements remain relevant.[6,7] These findings provide context for fixed rehabilitation but do not directly explain its age-related distribution in the present study. Moreover, restoration survival and complications were not evaluated, so higher restoration counts should not be interpreted as evidence of better clinical outcomes.

Implant-supported overdentures were significantly more frequent in elderly patients, and age showed a moderate positive correlation with implant-supported overdenture count. More extensive tooth loss and differences in the feasibility of fixed rehabilitation may contribute to this pattern. Nevertheless, bone availability, edentulism patterns, and treatment indications were not documented. The York and McGill consensus statements recommend mandibular two-implant overdentures as a first-choice standard of care for edentulous patients.[8,9] Favorable long-term clinical outcomes have also been reported in a 10-year trial.[10] These sources support the clinical role of implant-supported overdentures but do not establish that age alone determines their provision.

Patient satisfaction and functional outcomes are also relevant when considering removable implant rehabilitation. Scarano et al.[11] evaluated satisfaction with mandibular mini-implant-retained overdentures, while Srinivasan et al.[12] systematically reviewed oral function following implant-supported rehabilitation in completely edentulous patients. Their findings provide context for the potential benefits of implant-supported rehabilitation. However, the present study did not measure satisfaction or oral function, and the higher implant-supported overdenture count in elderly patients cannot be interpreted as evidence of greater benefit in this age group. Differences in implant dimensions, attachment systems, and treated arches also limit direct comparison with specific overdenture protocols. Attachment selection is a separate treatment consideration addressed by the systematic review of Sutariya et al.[13]

Conventional complete dentures were more frequent in elderly patients. Their strong positive correlation with implant-supported overdenture counts may reflect the provision of different removable prostheses in opposing arches, although arch-specific treatment combinations were unavailable. The negative correlation between implant-supported crown and implant-supported overdenture counts may reflect different rehabilitation strategies rather than patient preferences or treatment substitution.

Young adults had fewer conventional removable partial dentures than elderly patients. These restorations remained part of rehabilitation for some patients receiving dental implants. Remaining dentition, anatomical limitations, and financial circumstances may contribute to this pattern, but these factors were not recorded.

Males were significantly older than females, whereas implant and prosthetic restoration counts did not differ significantly between genders. These findings do not indicate gender-specific treatment preferences, and the comparisons did not account jointly for age and other clinical characteristics.

The present study evaluated treatment distribution rather than implant prognosis. Boboeva et al.[14] investigated factors associated with implant loss across age groups, an outcome distinct from the prosthetic restoration counts assessed here.

Bayındır et al.[15] examined the distribution of tooth-supported, implant-supported, and removable prosthetic treatments in a university clinic and reported the highest treatment volume among patients aged 50-64 years. Although their age categories and study population differed from ours, their findings provide a relevant comparison for the greater fixed restoration counts observed in middle-aged patients. Vemulapalli et al.[16] also reported associations between complete edentulism in older adults and socioeconomic characteristics and chronic conditions. These findings highlight factors that may contribute to differences in rehabilitation needs but were not recorded in the present study.

Evidence on implant loss or survival does not directly explain demographic differences in prosthetic treatment provision.

Limitations

Strengths of this study include its sample of 514 patients and the evaluation of both implant-supported and conventional restorations in routine university practice. Limitations include the retrospective, single-center design and unavailable information on socioeconomic status, systemic diseases, bone quality, patient preferences, edentulism patterns, treated arches, implant locations, and treatment indications. Restoration counts do not fully capture treatment complexity, maintenance needs, or clinical outcomes, and the observed associations do not establish causality.

Future multicenter prospective studies should incorporate clinical characteristics and patient-reported outcomes, reporting both restoration counts and treatment proportions to clarify age-related rehabilitation patterns.

CONCLUSION

This retrospective cross-sectional study identified age-related differences in implant number and the distribution of implant-supported and conventional prosthetic restorations. Young adults had fewer implants, middle-aged patients had more implant-supported and tooth-supported metal-ceramic crowns, and elderly patients had more implant-supported overdentures and conventional complete dentures. Implant and prosthetic restoration counts did not differ significantly between genders.

Implant number was positively correlated with implant-supported crown count, whereas implant-supported crown and implant-supported overdenture counts were negatively correlated. Within the limitations of this single-center study, these findings describe prosthetic treatment patterns and may inform planning alongside individual clinical needs, without establishing causal relationships or patient preferences.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was approved by the İnönü University Health Sciences Scientific Researches Ethics Committee (Date: 24.02.2026, Decision No: 2026/9438).

Informed Consent

This retrospective study used pre-existing anonymized patient data. No additional intervention was performed, and there was no direct patient contact. The study was approved by the Ethics Committee, and the requirement for written informed consent was waived by the ethics committee.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

Financial Disclosure

The authors received no financial support for the conduct or publication of this research.

Author Contributions

Concept: AK; Design: AK; Control: AK; Resources: AK, FÖ; Materials: AK; Data Collection and/or Processing: AK, FÖ; Analysis and/or Interpretation: AK; Literature Review: AK; Writing the Article: AK, FÖ; Critical Review: AK, FÖ. All authors have read and approved the final version of the manuscript.

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Journal of Dental Sciences and Education

Case Report

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Fiber-reinforced direct restoration of an endodontically treated molar using polyethylene ribbon and short fiber-reinforced composite: a case report

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ABSTRACT

Restoring endodontically treated posterior teeth with extensive tissue loss is challenging because of reduced structure and shrinkage stress. This report describes a residual-wall-thickness-guided fiber-reinforced direct restoration. A maxillary left first molar in a 45-year-old male, root-canal treated and restored nine years earlier without fiber reinforcement or cuspal coverage, showed cavitated secondary caries at both proximal margins. Caries removal left a wide mesio-occluso-distal cavity with a 1.5-mm residual palatal wall. Under rubber dam, the canal orifices were sealed and a polyethylene ribbon with a short fiber-reinforced composite base placed. The thinned palatal cusps were covered, the enamel-intact buccal cusps preserved, and the surface finished with supra-nano composite. At 1 month all World Dental Federation (FDI) parameters were clinically excellent; at 6 months only surface staining changed, without fracture or retention loss. These findings document early clinical behavior only; longer follow-up is needed before recommending this approach over indirect restorations.

Keywords: Root canal therapy, composite resins, dental restoration failure, polyethylene, short-fiber-reinforced compositen

INTRODUCTION

Endodontically treated posterior teeth are biomechanically weakened by cumulative tissue loss from access preparation and from the caries or restorations that necessitated it; under occlusal load, cuspal deformation and the risk of unrestorable vertical fracture rise.[1] Mesio-occluso-distal (MOD) cavities are particularly detrimental, removing both marginal ridges and leaving tall, unsupported cusps. MOD preparation alone has been reported to reduce relative cuspal stiffness by 63% in extracted premolars,[2] so this configuration is among the most biomechanically compromised in the posterior dentition.

Secondary caries is a leading reason for replacing posterior direct restorations,[3] and each replacement cycle removes more tooth structure, leaving the tooth weaker than before.[4,5] The conventional alternative, indirect cuspal-coverage restoration, sacrifices further sound tissue and adds cost and visits.[6]

Direct composites are threatened by polymerization shrinkage stress at the adhesive interface, greatest in cavities with a high configuration factor (C-factor), and by functional stress in the remaining tissue. An ultra-high-molecular-weight polyethylene ribbon bridges the cavity, redistributing load and arresting crack propagation.[7] Short fiber-reinforced composites (SFRCs) with randomly oriented E-glass fibers deflect cracks and provide a dentin-replacing core of intermediate elastic modulus.[8] This report describes a fiber-reinforced direct restoration of such a molar; its contribution is a residual-wall-thickness-driven decision to cover only the thinned palatal cusps while preserving the enamel-intact buccal ones, documented with standardized criteria.

CASE REPORT

This report follows the CARE guidelines.[9] A 45-year-old male (American Society of Anesthesiologists class I), taking no regular medication and reporting no parafunctional habit, presented for a routine check-up. The maxillary left first molar (tooth 26) had been root-canal treated about nine years earlier and restored with direct composite, without fiber reinforcement or cuspal coverage.

The tooth was asymptomatic, with normal percussion and palpation, physiological mobility, and probing depths ≤3 mm. The antagonist tooth 36 was restored and in stable occlusal contact, excursions were canine-guided, and no wear facets were present. Cavitated secondary caries was present at both proximal margins with loss of the mesial marginal ridge (**Figure 1a**); preoperative panoramic radiography (**Figure 1b**) showed a root canal filling extending to the radiographic apex, with no periapical radiolucency and no evident interproximal bone loss. No preoperative periapical radiograph of this tooth was available, and panoramic imaging does not permit a reliable assessment of interproximal bone levels or of the density of the root canal filling; the preoperative radiographic status is therefore presented as a cropped detail of the panoramic image in the region of tooth 26, and both points are acknowledged among the limitations. Caries risk was

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high because of the active proximal lesions and interproximal plaque retention; fluoride varnish, interdental cleaning, and six-monthly recall were prescribed.

Because both proximal lesions extended beneath the restoration, replacement rather than repair was indicated. Indirect cuspal-coverage options and a fiber post were discussed; owing to cost and time constraints the patient chose the single-visit fiber-supported approach, including possible cuspal coverage, and consented in writing after being told the long-term prognosis is not established. The timeline is given in **Table 1**.

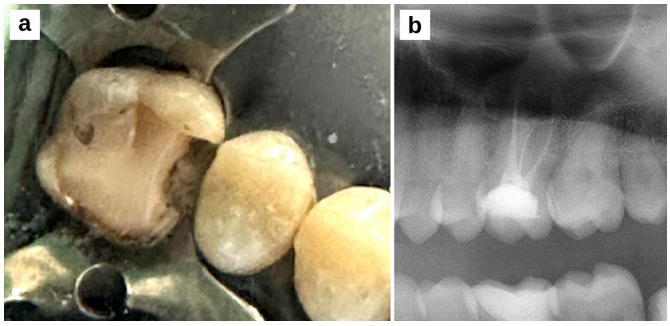

Figure 1. Preoperative documentation of tooth 26. (a) Clinical view after rubber-dam isolation, showing cavitated secondary caries at both proximal margins and loss of the mesial marginal ridge. (b) Cropped detail of the preoperative panoramic radiograph in the region of tooth 26, showing the root canal filling extending to the radiographic apex with no periapical radiolucency

The palatal cusps were therefore reduced 2 mm, the buccal cusps were left intact, and a sectional matrix with a separating ring (Quickmat Deluxe) was used sequentially for the mesial and distal walls. Enamel was selectively etched with 35% phosphoric acid (Promida Proetch Etching Gel) for 30 s, and a self-etch adhesive (Tokuyama Bond Force II) was applied and light-cured per manufacturer instructions. The canal orifices were sealed with a flowable composite (Polofil NHT Flow), creating a flat base for the ribbon. A 3-mm-wide polyethylene ribbon (InFibra) was cut into two pieces, wetted with the same adhesive uncured, and adapted mesio-distally (one onto the pulpal floor and one against the reduced palatal wall) then light-cured (**Figure 2b**). A 4-mm short fiber-reinforced composite (everX Posterior) was applied in two 2-mm increments to limit shrinkage stress and light-cured for 20 s each, serving as a dentin-replacing base extending beneath the covered palatal cusps (**Figure 2c**). The occlusal and external surfaces were completed with a 2-mm layer of shade A2 supra-nano spherical composite (Estelite Posterior), each increment cured for 20 s with an LED unit delivering 1400 mW/cm² (Vega). The restoration was finished and polished, and occlusion verified in centric and excursive movements (**Figure 2d**).

Evaluations used FDI World Dental Federation (FDI) criteria[10] and were performed by the treating dentist. The tooth was asymptomatic at both recalls; at 1 month, all FDI criteria (esthetic: surface luster, staining, form; functional: fracture, marginal adaptation, wear; biological: post-op sensitivity, caries recurrence) were scored 1. At 6 months, only surface staining scored 2; all others remained 1, and the restoration was repolished. Proximal and occlusal contacts were maintained (**Figure 3a**), with no periapical or sub-restoration radiolucency (**Figure 3b**). The patient reported satisfaction with appearance and function.

Table 1. Case timeline

Time	Event
2017 (per patient dental records)	Root canal treatment of tooth 26 and direct composite restoration without fiber reinforcement or cuspal coverage
2 February 2026	Routine examination: cavitated secondary caries detected at both proximal margins; caries risk assessed as high, preventive measures prescribed
2 February 2026 (same visit)	Fiber-reinforced direct restoration: selective enamel etching, orifice sealing, two 3-mm polyethylene ribbon strips, 4-mm short fiber-reinforced composite base, palatal cuspal coverage, 2-mm covering composite
2 March 2026	One-month recall: all FDI parameters scored 1 (clinically excellent)
3 August 2026	Six-month recall: surface staining scored 2 (clinically good), all other parameters 1, restoration repolished

FDI: World Dental Federation

All procedures were completed in one visit (materials, manufacturers, and locations in **Table 2**). After infiltration anesthesia, the field was isolated with a rubber dam. Removal of the old restoration and caries produced a wide MOD cavity with loss of both marginal ridges, interruption of the oblique ridge, and supragingival margins. Caliper measurement at the cavity floor gave residual wall thicknesses of 1.5 mm palatally and 2.5 mm buccally, the latter enamel-intact (**Figure 2a**).

Table 2. Materials used

Purpose	Trade name	Manufacturer
Rubber-dam clamp	Carl Martin Clamp (No. 8)	Carl Martin, Solingen, Germany
Sectional matrix	Quickmat Deluxe sectional matrix systems	Polidentia, Lugano, Switzerland
Selective enamel etching (35% phosphoric acid)	Promida Proetch Etching Gel	Promida Dental Materials, Eskişehir, Turkiye
Self-etch adhesive	Tokuyama Bond Force II	Tokuyama Dental, Tokyo, Japan
Flowable composite (orifice barrier)	Polofil NHT Flow	Voco, Cuxhaven, Germany
Polyethylene ribbon (3 mm, two strips)	InFibra	Bioloren, Saronno, Italy
Short fiber-reinforced composite	everX Posterior	GC Corporation, Tokyo, Japan
Covering composite (shade A2)	Estelite Posterior	Tokuyama Dental, Tokyo, Japan
LED curing unit (1400 mW/cm²)	Vega	Dentac, İstanbul, Turkiye
Finishing discs	Sof-Lex	3M Oral Care, St. Paul, MN, USA
Polishing wheels	Twist Dia	Kuraray Noritake Dental, Tokyo, Japan

NHT: Nanohybrid technology, mm: Millimeter, GC: General Chemical, LED: Light-emitting diode, mW/cm²: Milliwatts per square centimeter, 3M: Minnesota Mining and Manufacturing, MN: Minnesota, USA: United States of America

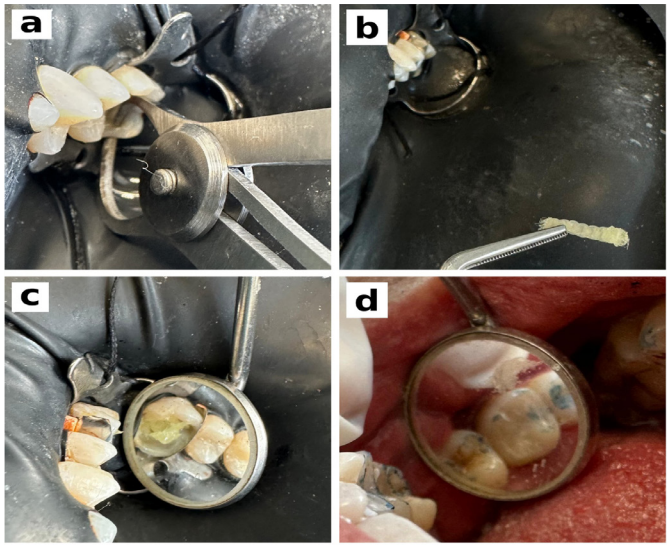

Figure 2. Stages of the fiber-reinforced direct composite restoration. (a) Caliper used to measure the residual palatal wall thickness at the cavity floor after removal of the old restoration and caries; (b) the two 3-mm-wide polyethylene ribbon strips wetted with uncured adhesive resin before placement on the pulpal floor and against the reduced palatal wall; (c) mirror view of the short fiber-reinforced composite base over the ribbons, extending beneath the reduced palatal cusps; (d) mirror view of the completed restoration after finishing and polishing; the blue articulating-paper marks show the centric occlusal contacts recorded after occlusal adjustment

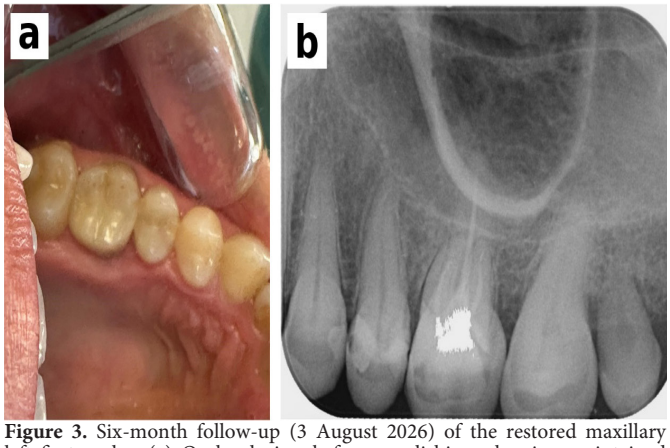

Figure 3. Six-month follow-up (3 August 2026) of the restored maxillary left first molar. (a) Occlusal view before repolishing, showing maintained proximal and occlusal contacts and superficial surface staining (FDI score 2); (b) periapical radiograph showing no periapical or sub-restoration radiolucency

FDI: World Dental Federation

DISCUSSION

Three design elements (an SFRC base, a ribbon, and selective cuspal coverage) plausibly contributed to the intact six-month outcome. In a high C-factor MOD cavity, an SFRC base reduces the volume of conventional composite polymerized against confined walls and, through its crack-arresting fiber network, helps absorb shrinkage stress;[8,11] in vitro, such restorations match composite inlays in fatigue survival.[12] The ribbon, adapted mesio-distally over the pulpal floor and against the reduced palatal wall, is intended to redistribute load across the residual walls and to deflect cracks running from the cavity floor toward the cusps; in vitro, polyethylene fibre reinforcement of endodontically treated premolars and molars has been shown to reduce cusp deflection, to increase fracture strength and to produce more favourable, repairable fracture patterns.[7,13] These biomechanical effects were not measured in the present case; they are inferred from the cited laboratory evidence and are presented as the design rationale rather than as a demonstrated effect.

Cuspal coverage was decided on residual wall thickness: 2 mm is recommended for non-functional cusps and enamel cracking increases when walls thin to 1 mm;[14] in vitro premolar data support the same 2-mm threshold.[15] Because the palatal cusps of a maxillary molar are centric-holding, a more cautious threshold than the one reported for non-functional cusps was adopted in this case; finite element analysis indicates that the preservation of functional cusps affects stress distribution in onlay-restored molars differently from the preservation of non-functional cusps.[16] No threshold specific to centric-holding cusps was identified in the literature, so this decision is presented as a case-specific clinical judgement rather than as an evidence-based cut-off. The measured palatal thickness of 1.5 mm was in any event below the 2-mm threshold cited above, and the rigidity-lending oblique ridge had also been interrupted. Coverage may therefore convert tensile loading of the thin cusps into more distributed compressive loading; preserving the buccal cusps kept the preparation conservative. A randomized trial found direct SFRC restorations comparable to composite onlays in complex molar cavities at one year.[17] A fiber post was not indicated, since post-space preparation removes dentin without enhancing cuspal fracture resistance.[6]

The six-month outcome is consistent with short-term data reporting high survival for SFRC restorations in large posterior cavities, although that review found no clear clinical advantage over conventional composites despite in vitro superiority.[18] Six months, however, tests the adhesive interface more than fatigue resistance, so these findings document early clinical behavior rather than durability. The previous restoration survived nine years and failed by caries rather than fracture, a presentation consistent with marginal-adhesive failure, although the mechanism cannot be established from a single case; nine years therefore represents a realistic benchmark against which the present restoration should be judged. The only deviation is surface discoloration. This is probably due to surface abrasion of the covering composite. Opening the E-glass fibers to the oral environment increases water absorption. For this reason, the surface was covered with an overlying composite.[19] Ribbon placement is technique sensitive. An air bubble or inadequate adaptation to the walls reduces load transfer.

A single case does not permit any inference about long term survival. Because the contributions of the ribbon and of the SFRC cannot be separated from each other, fiber reinforcement is presented as a design rationale rather than as a measured effect. Because the orifice barrier, the polyethylene ribbon, the SFRC base and the selective cuspal coverage were all applied at the same visit, the design is methodologically inseparable. The contribution of any single component to the six-month outcome cannot be quantified. No conclusion can be reached about the mechanical benefit of the ribbon compared with that of the SFRC base. Separating these effects requires a controlled in vitro or randomized design in which each element is varied independently. For this reason, the present report should be read as a documented clinical application of the combined technique rather than as evidence regarding any one of its components. The evaluation was unblinded and was performed by a single examiner without a comparison group. For this reason, the possibility of bias in the FDI scores cannot be excluded.

Because periapical rather than bitewing radiography was used for follow up imaging, proximal changes beneath the restoration may have been underestimated. Periapical radiography is inadequate for the endpoints that matter most in a restoration placed because of proximal secondary caries (interproximal marginal adaptation, micro gap formation and recurrent proximal caries). Therefore, bitewing radiography will be used at the subsequent recalls. Documentation is a further limitation: the clinical photograph in Figure 1a is the only preoperative clinical image of this tooth and was obtained under routine clinical conditions. Consequently, its resolution and illumination limit detailed assessment of the preoperative cavity margins. No preoperative periapical radiograph was available, and the preoperative panoramic image presented in Figure 1b is inherently limited by superimposition, low spatial resolution and geometric distortion. For this reason, neither the interproximal bone level nor the density of the root canal filling could be assessed preoperatively with the accuracy that a periapical film would provide.

CONCLUSION

In an endodontically treated maxillary first molar with a residual palatal wall thickness of 1.5 mm, a fiber-reinforced direct restoration combining a polyethylene ribbon, an SFRC base, and selective palatal cuspal coverage was clinically acceptable at six months. These findings document early clinical behavior only; longer-term evidence is required before it can be recommended as an alternative to indirect restorations.

ETHICAL DECLARATIONS

Informed Consent

Written informed consent was obtained from the patient included in this report. Signed consent forms are retained by the authors and are available upon request.

Peer Review Process

This report underwent external peer review.

Conflict of Interest

The author declares no conflicts of interest.

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Author Contributions

The author is solely responsible for the entirety of conception, execution, analysis, and writing of the manuscript.

Editor Note

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Case Report

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Root coverage of an isolated gingival recession using the tunnel technique and a de-epithelialized connective tissue graft: an 8-month follow-up case report

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ABSTRACT

Gingival recession is a common mucogingival deformity that may lead to esthetic concerns, dentin hypersensitivity, and impaired plaque control. The tunnel technique combined with a connective tissue graft is widely used for root coverage because of its favorable clinical and esthetic outcomes. This case report describes the management of deep isolated Cairo RT1 gingival recession defects using the tunnel technique in combination with a de-epithelialized connective tissue graft. A 23-year-old healthy female presented with isolated gingival recession affecting teeth #25 and #26, accompanied by esthetic concerns, dentin hypersensitivity, and discomfort during toothbrushing. The recession depths were 6 mm and 8 mm, respectively, with limited keratinized tissue. Following root surface preparation, root coverage was performed using the tunnel technique and a de-epithelialized connective tissue graft harvested from the palate. Healing was uneventful throughout the postoperative period. At the 8-month follow-up, complete root coverage was achieved at tooth #25, whereas 75% root coverage was obtained at tooth #26. Keratinized tissue width increased at both treated sites, dentin hypersensitivity and toothbrushing discomfort resolved completely, and the patient reported a high level of esthetic satisfaction. In this case, the tunnel technique combined with a de-epithelialized connective tissue graft resulted in substantial root coverage, favorable soft tissue healing, and satisfactory esthetic and functional outcomes at the 8-month follow-up.

Keywords: Gingival recession, tunnel technique, connective tissue graft, root coverage

INTRODUCTION

Gingival recession (GR) is defined as the apical displacement of the gingival margin beyond the cemento-enamel junction (CEJ), resulting in exposure of the root surface. It is one of the most prevalent mucogingival deformities encountered in clinical practice and may occur in individuals with healthy periodontal tissues as well as in patients with a history of periodontal disease. The prevalence and severity of GR increase with age, although localized recession defects are frequently observed in young adults, particularly in the presence of predisposing anatomical or behavioral factors. The etiology of GR is multifactorial and includes thin periodontal phenotype, traumatic toothbrushing, plaque-induced inflammation, high frenal attachment, orthodontic tooth movement beyond the alveolar envelope, periodontal disease, and iatrogenic restorative or surgical procedures. In particular, inappropriate toothbrushing techniques, excessive brushing frequency, and the use of toothbrushes with hard bristles have been identified as potential contributing factors to gingival recession. In addition to compromising smile esthetics, gingival recession may lead to dentin hypersensitivity, root caries, non-carious cervical lesions, plaque retention, and impaired plaque control, ultimately reducing patients' oral health-related quality of life. Consequently, successful management requires not only correction of the soft tissue defect but also elimination of the underlying etiologic factors. The 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions further improved the diagnostic and prognostic assessment of gingival recession through the Cairo classification, which is based on interproximal clinical attachment loss and has become the current reference system for root coverage procedures.[1-3]

Numerous periodontal plastic surgical techniques have been described for the treatment of gingival recession, including free gingival grafts, laterally positioned flaps, coronally advanced flap (CAF), subepithelial connective tissue grafts (SCTGs), tunnel techniques, and the use of soft-tissue substitutes or biologic adjuncts. Among these approaches, SCTG combined with coronal soft tissue advancement is widely regarded as the gold standard because of its predictable root coverage, increased gingival thickness, enhanced keratinized tissue width, and excellent long-term stability. During the last decade, the tunnel technique has gained increasing popularity as a minimally invasive alternative because it preserves the interdental papillae, avoids vertical

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releasing incisions, and maintains an adequate blood supply from both the overlying flap and the underlying periosteum. These biological characteristics favor graft revascularization, improve wound healing, minimize postoperative morbidity, and provide excellent esthetic integration. Recent systematic reviews and meta-analyses have demonstrated that tunnel-based procedures achieve root coverage outcomes comparable to or, in selected clinical situations, superior to those obtained with conventional CAF techniques while maintaining high patient satisfaction and favorable esthetic outcomes.[4-7]

More recently, increasing attention has been directed toward the use of de-epithelialized connective tissue grafts (DCTGs) harvested from free gingival grafts. Compared with conventionally harvested SCTGs, DCTGs provide a denser connective tissue architecture with reduced adipose and glandular tissue content, potentially facilitating graft adaptation and revascularization beneath the tunnel flap. Current evidence indicates that DCTGs provide clinical outcomes comparable to conventional SCTGs with respect to recession reduction, complete root coverage, clinical attachment gain, gingival thickness, and keratinized tissue width. Furthermore, careful case selection, microsurgical principles, and meticulous soft tissue handling have been recognized as key determinants of successful root coverage irrespective of the harvesting technique. Although high-level evidence supporting tunnel-based root coverage procedures continues to expand, well-documented clinical case reports remain valuable for demonstrating the practical application of contemporary surgical concepts and illustrating soft tissue healing and maturation under routine clinical conditions.[8-11] Therefore, this case report describes the management of gingival recession defects using the tunnel technique combined with a de-epithelialized connective tissue graft, highlighting the surgical protocol and the clinical outcomes observed at the 8-month follow-up.

CASE REPORT

A 23-year-old healthy female patient presented to the Department of Periodontology with the chief complaint of gingival recession associated with esthetic concerns, dentin hypersensitivity, and discomfort during toothbrushing in the left maxillary posterior region. The patient had no history of systemic disease, medication use, smoking, or previous periodontal surgery. Clinical examination revealed good oral hygiene with minimal plaque accumulation, and no bleeding on probing was detected at the affected teeth. The gingival phenotype in the involved region was classified as thick.

Clinical examination revealed localized gingival recession defects affecting teeth #25 and #26, both extending to the mucogingival junction and classified as Cairo recession type 1 (RT1). The recession depth, measured from the cemento-enamel junction (CEJ) to the free gingival margin, was 6 mm at tooth #25 and 8 mm at tooth #26. The width of keratinized tissue was 1 mm at tooth #25, whereas no measurable keratinized tissue was present at tooth #26. Probing depths were 1 mm at both sites, with no evidence of interproximal attachment loss. Both teeth responded positively to pulp vitality testing and exhibited no mobility. No non-carious cervical lesions, cervical abrasions, or radiographic evidence of alveolar bone loss were observed.

Based on the patient's history and clinical findings, the recession defects were considered to be primarily associated with traumatic toothbrushing. The localized hyperkeratinization of the interdental papilla between teeth #25 and #26 was considered to have encouraged excessive brushing in this area, thereby contributing to the development of the recession defects. Considering the depth of the recession defects, the inadequate width of keratinized tissue, the absence of interproximal attachment loss, and the patient's symptoms and esthetic concerns, root coverage using the tunnel technique combined with a de-epithelialized connective tissue graft (DCTG) was planned. The patient was informed about the proposed surgical procedure, alternative treatment options, potential risks, and expected outcomes, and written informed consent was obtained before surgery (**Figure 1**).

Figure 1. Preoperative clinical appearance demonstrating isolated deep Cairo RT1 gingival recession defects affecting teeth #25 and #26

RT1: Recession type 1

Surgical Procedure

Following completion of initial periodontal therapy and reinforcement of oral hygiene instructions, the surgical procedure was performed under local anesthesia using 2% lidocaine with 1:100,000 epinephrine. After achieving profound anesthesia at both the recipient and donor sites, thorough root surface debridement and root planing were performed using Gracey curettes, followed by copious irrigation with sterile saline solution to prepare the exposed root surfaces for graft adaptation. No chemical root surface conditioning or detoxification agents, such as ethylenediaminetetraacetic acid (EDTA) or citric acid, were applied during the procedure (**Figure 2**).

Figure 2. Root surface debridement and root planing performed using Gracey curettes before tunnel preparation

Intrasulcular incisions were made around teeth #25 and #26. A split-thickness tunnel was carefully prepared using a specialized tunneling instrument set (Procut Tunnel Kit), with preservation of the interdental papillae. The tunnel was extended beyond the mucogingival junction to allow passive coronal advancement of the flap without tension. Particular care was taken to preserve the periosteal bed, thereby maintaining adequate vascular supply and promoting graft revascularization.

A free gingival graft measuring approximately 12×5 mm was harvested from the palatal donor site and subsequently de-epithelialized extraorally to obtain a connective tissue graft approximately 1.5 mm in thickness. Following graft harvesting, a Spongostan® absorbable gelatin sponge was placed over the donor site to facilitate hemostasis, and the donor site was sutured with 3-0 silk sutures (**Figure 3**).

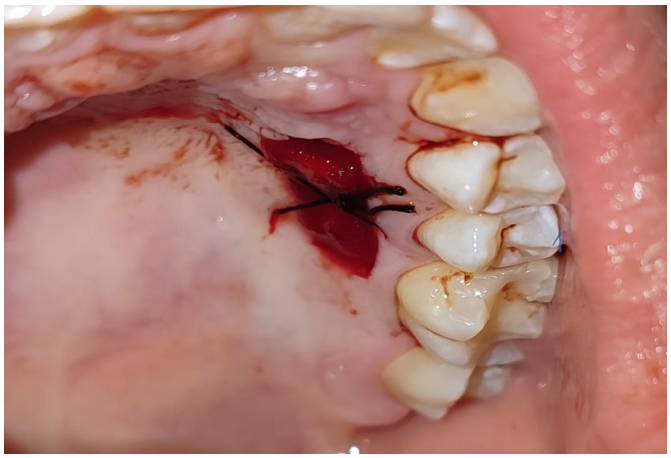

Figure 3. Palatal donor site immediately after graft harvesting, placement of Spongostan®, and closure with 3-0 silk sutures

The de-epithelialized connective tissue graft was gently inserted into the prepared tunnel and stabilized using 6-0 polypropylene sutures, ensuring intimate adaptation to the exposed root surfaces. Subsequently, the tunnel flap was passively advanced coronally to completely cover both the graft and the exposed root surfaces. Coronal positioning was maintained using suspended sling sutures, which were stabilized by bonding them to the buccal surfaces of the involved teeth with flowable composite resin. Flap stability and passive adaptation were verified before completion of the procedure, and adequate hemostasis was achieved (**Figure 4**).

Figure 4. Immediate postoperative clinical appearance following tunnel technique and placement of the de-epithelialized connective tissue graft

Postoperative instructions were provided, including avoidance of mechanical trauma and toothbrushing at the surgical site, adherence to a soft diet, and maintenance of appropriate oral hygiene measures. Postoperative medications included etodolac 400 mg (Etol Fort), administered twice daily for the first 3 days and subsequently as needed for pain management, and amoxicillin/clavulanic acid 1 g (Augmentin BID), prescribed twice daily for 7 days. In addition, the patient was instructed to use a mouth rinse containing 0.12% chlorhexidine gluconate and 0.15% benzydamine hydrochloride (Kloroben, Drogsan, Turkiye) two to three times daily for 10 days to support postoperative plaque control.

Clinical Outcomes and Follow-Up

The postoperative healing period was uneventful, and no complications, including infection, flap necrosis, graft exposure, or excessive bleeding, were observed. Sutures were removed 2 weeks after surgery, revealing satisfactory healing at both the recipient and donor sites (**Figure 5**). The palatal donor site demonstrated favorable epithelialization without signs of infection, delayed healing, or patient-reported discomfort, whereas the recipient site exhibited favorable soft tissue adaptation and maintenance of flap stability (**Figure 6**).

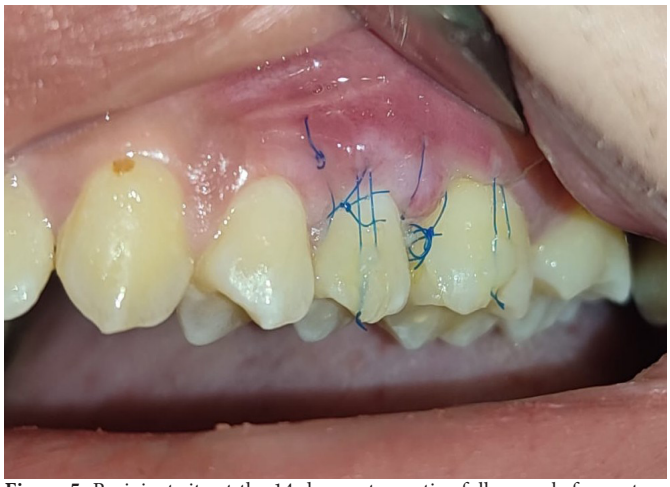

Figure 5. Recipient site at the 14-day postoperative follow-up before suture removal, demonstrating favorable early soft tissue healing

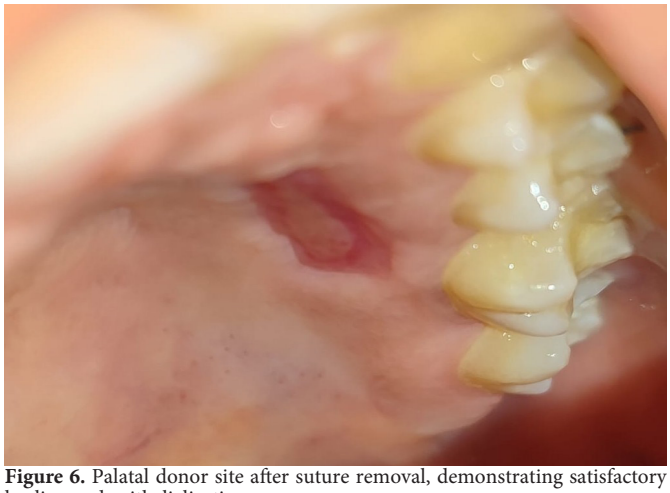

Figure 6. Palatal donor site after suture removal, demonstrating satisfactory healing and epithelialization

At the 3-month follow-up, the patient demonstrated inadequate plaque control in the treated area. Oral hygiene instructions were reinforced, and the patient was encouraged to improve plaque control to maintain the clinical outcomes (**Figure 7**).

Figure 7. Clinical appearance at the 3-month follow-up showing stable root coverage and early soft tissue maturation

At the 8-month follow-up, the clinical outcomes remained stable. Complete root coverage was achieved at tooth #25, whereas a residual recession depth of 2 mm remained at tooth #26, corresponding to approximately 75% root coverage. The width of keratinized tissue increased from 1 mm to 2 mm at tooth #25 and from 0 mm to 1 mm at tooth #26. Probing depths remained 1 mm, and no bleeding on probing was detected (**Figure 8**). The patient reported complete resolution of dentin hypersensitivity and discomfort during toothbrushing and expressed a high level of satisfaction with the esthetic outcome. Clinical examination revealed healthy periodontal tissues, satisfactory integration of the grafted tissues with the surrounding gingiva, and maintenance of the clinical improvements at the 8-month follow-up despite the temporary decline in plaque control observed at the 3-month visit (**Table**).

Figure 8. Clinical outcome at the 8-month follow-up demonstrating stable root coverage, increased keratinized tissue width, and favorable soft tissue integration

Table. Clinical outcomes following root coverage surgery

	Baseline		8-month follow-up	
Parameter	**Tooth #25**	**Tooth #26**	**Tooth #25**	**Tooth #26**
Recession depth (mm)	6	8	0	2
Root coverage (%)	-	-	100	75
Keratinized tissue width (mm)	1	0	2	1
Probing depth (mm)	1	1	1	1
Bleeding on probing	Negative	Negative	Negative	Negative
Dentin hypersensitivity	Present		Resolved	
Toothbrushing discomfort	Present		Resolved	
Patient satisfaction	-		High	

Clinical measurements are presented separately for teeth #25 and #26 at baseline and at the 8-month follow-up. Root coverage percentages were calculated based on the reduction in recession depth relative to baseline measurements. Patient-reported outcomes, including dentin hypersensitivity, toothbrushing discomfort, and esthetic satisfaction, were assessed at the patient level

DISCUSSION

The primary objective of root coverage procedures is not only to achieve complete coverage of the exposed root surface but also to improve soft tissue quality, eliminate dentin hypersensitivity, and enhance patient satisfaction. In the present case, the tunnel technique combined with a de-epithelialized connective tissue graft resulted in complete root coverage at tooth #25 and 75% root coverage at tooth #26, accompanied by an increase in keratinized tissue width, complete resolution of dentin hypersensitivity and toothbrushing discomfort, and a high level of patient satisfaction after an 8-month follow-up. These findings are consistent with previous randomized clinical trials reporting favorable root coverage outcomes, satisfactory esthetic integration, and positive patient-reported outcomes following tunnel-based procedures.[2,12]

Although subepithelial connective tissue grafts remain the reference standard for periodontal plastic surgery, de-epithelialized connective tissue grafts have recently emerged as a reliable alternative because they provide comparable clinical outcomes while allowing a more homogeneous connective tissue graft to be obtained. In a randomized clinical trial, Bakhishov et al.[13] reported mean root coverage rates of 91.72%±16.59% for de-epithelialized gingival grafts and 84.72%±19.72% for conventionally harvested subepithelial connective tissue grafts combined with the tunnel technique at the 12-month follow-up. Histological analysis further demonstrated that de-epithelialized grafts contained less adipose and glandular tissue, supporting their biological suitability for mucogingival surgery. The favorable graft integration and soft tissue maturation observed in the present case are consistent with these findings, although longer follow-up is required to establish their stability.[2,9,13,14]

The favorable outcome observed in this case may also be attributed to the biological advantages of the tunnel technique. Preservation of the interdental papillae and maintenance of the periosteal blood supply promote graft revascularization while minimizing surgical trauma. Furthermore, the absence of vertical releasing incisions improves tissue blending and reduces scar formation, particularly in esthetically demanding areas. González-Febles et al.[12] demonstrated that tunnel and coronally advanced flap techniques combined with connective tissue grafts provide comparable root coverage and esthetic outcomes, while tunnel procedures may offer favorable patient-reported outcomes because of their minimally invasive nature. Similarly, previous randomized clinical trials have shown that tunnel techniques are associated with high percentages of complete root coverage and excellent root coverage esthetic scores.[12,15]

Complete root coverage was achieved only at tooth #25, whereas a residual recession of 2 mm remained at tooth #26. This difference may be explained by the greater baseline recession depth at tooth #26 (8 mm versus 6 mm), despite both defects being classified as Cairo RT1. Previous clinical studies have suggested that baseline recession depth is an important predictor of root coverage outcomes, with deeper recession defects generally exhibiting lower probabilities of complete root coverage. Nevertheless, despite incomplete root coverage at tooth #26, the patient reported complete resolution of symptoms and expressed a high level of esthetic satisfaction, emphasizing that treatment success should not be evaluated

solely according to complete root coverage but also according to patient-centered outcomes.[2,7]

CONCLUSION

An interesting finding of the present case was the temporary deterioration in plaque control observed at the 3-month follow-up. Following reinforcement of oral hygiene instructions, plaque control improved, and the clinical outcomes remained stable at the 8-month evaluation. This observation highlights the importance of supportive periodontal therapy and continued patient motivation in maintaining favorable clinical outcomes following mucogingival surgery. The present case report has certain limitations. First, the findings are based on a single patient and therefore cannot be generalized to a broader population. Second, although favorable clinical outcomes were observed at the 8-month follow-up, this period is insufficient to establish the long-term stability of the achieved root coverage. Longer follow-up periods are necessary to assess potential changes in gingival margin position and soft tissue stability over time. Furthermore, the absence of a comparison group prevents conclusions regarding the relative effectiveness of this surgical approach compared with alternative root coverage techniques.

ETHICAL DECLARATIONS

Informed Consent

Written informed consent was obtained from the patient included in this report. Signed consent forms are retained by the authors and are available upon request.

Peer Review Process

This report underwent external peer review.

Conflict of Interest

The author declares no conflicts of interest.

Financial Disclosure

This case report did not receive any financial support.

Author Contributions

The author is solely responsible for the entirety of conception, execution, analysis, and writing of the manuscript.

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