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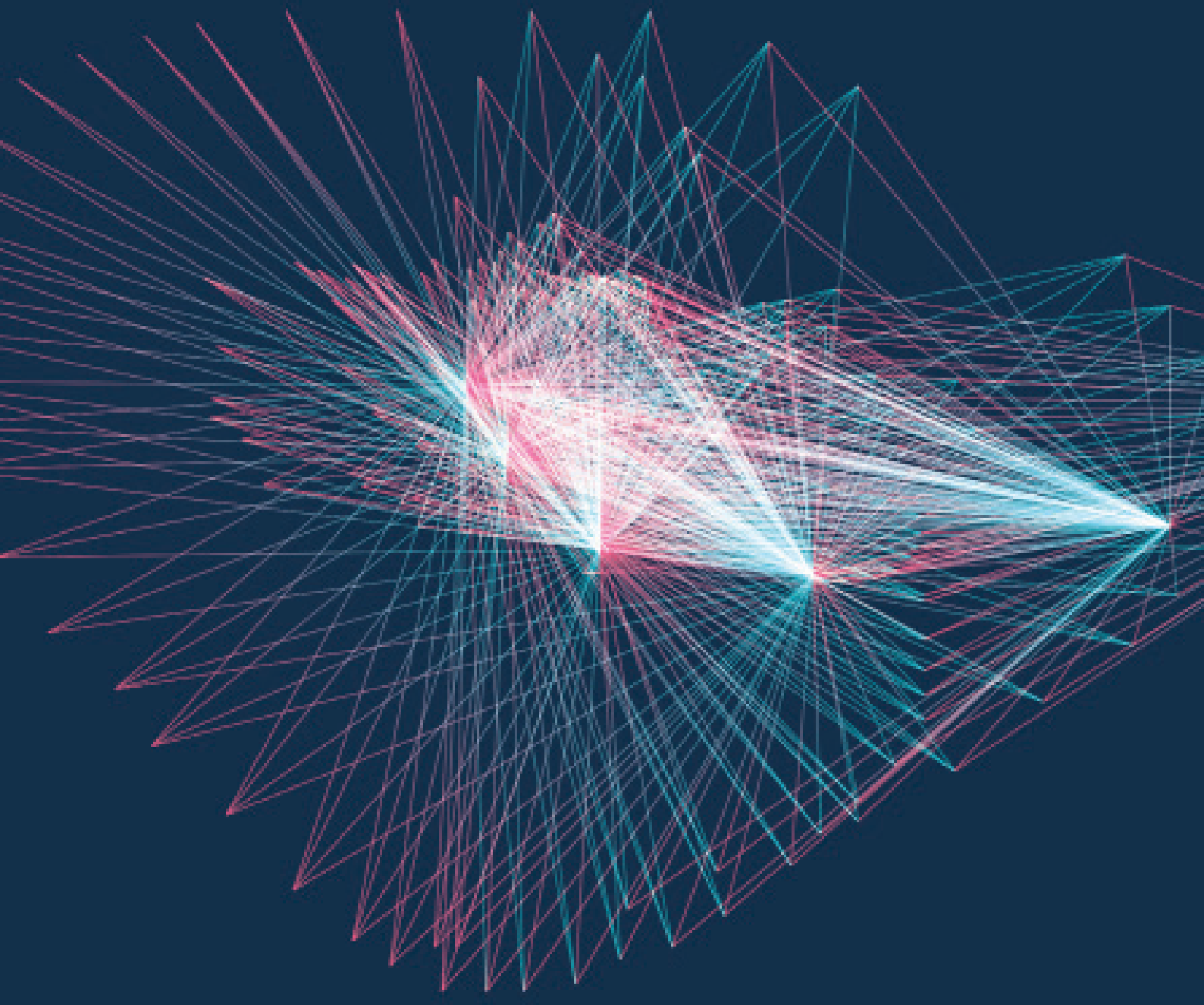

Chiang Mai University's Faculty of Dentistry publishes academic research articles in the newly titled - **Oral Sciences Reports,** which was previously known as *Chiang Mai Dental Journal (CMDJ)*. The journal was originally established for the purposes of publishing academic research articles by the Faculty of Dentistry at Chiang Mai University in 1977. In the current report, editors and experts in their respective fields review articles received from authors prior to being published to ensure that the content of all articles is up-to-date, universal, logical, and in accordace with academic principles so the reader can apply knowledge and cite works in the development of dentistry for the purposes of advancing future research while being beneficial to patients and society.

At present, Oral Sciences Reports openly receives all submissions through an online journal review process system. The new online system also allows reviewers and researchers an ability to read 3 issues each year.

Aim and Scope of the journal

To compile research and content that is up to date and usable to all branches of dentistry and related fields. The articles in Oral Sciences Reports are fundamental research work, including original articles, review articles, case reports/ series, short communications, and letters to the editor.

Policy

Accepted articles will be fairly reviewed by the editors and experts with full transparency through the following process.

1. The articles must be correct according to academic principles and not duplicate works that have been previously published.
2. The articles will be considered and reviewed through a non-bias process by concealing the names of authors and related persons in the considered documents while also concealing the names of the experts and reviewers who review the articles (double-blind review).
3. The review process can be tracked online. The article authors can review the status of their article and are able to follow up on the article evaluation through the online process. The duration of each step is closely monitored so that the articles can be published on time.
4. Authors of articles are responsible to review and verify the accuracy of the text, images, tables in the articles before publication.
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Indexing

Thai Journal Citation Index Centre (TCI) Tier 1
Asian Citation Index (ACI)
Google Scholar

Editorial Board

Types of Submission

Oral Sciences Reports invites the following submissions:

1. Original Articles — Original contributions of research reports or unpublished recent academic research to the development and applications in dentistry and related fields. The original article must not exceed 4000 words in length and must contain no more than 10 figures and tables in total.
2. Review Articles — Comprehensive reviews of special areas of focus in dentistry and related fields. Articles that contain important collected data from numerous books or journals and from the writer's experience. Information should be described, reviewed, compared, and analyzed. The review article must not exceed 4000 words in length and must contain no more than 10 figures and tables in total.
3. Systematic Reviews — Clearly formulated reviews that uses systematic and reproducible methods to identify, select and critically appraise all relevant research, and to collect and analyze data from the studies that are included in the review.
4. Case Reports/Series — Original findings that highlight novel technical and/or clinical aspects in dentistry and related fields which include clinical symptoms, diagnosis, patient care, treatment, follow-up, and evaluation. The report must not exceed 2500 words in length and must contain no more than 5 figures.
5. Letters to the Editor — Commentaries on published papers in the journal and other relevant matters that must not exceed 1000 words in length
6. Short Communications — Original contributions describing new developments of high impact that justify expedited review. The report must not exceed 2000 words in length and must contain no more than 3 figures.

Submission Checklist

Authors should ensure to prepare the following items for submission. Failure to complete the required items may contribute to the delay of publication process. Please check the relevant section in this guideline for more details.

1. Title page — Must include title of the article, author names and affiliations. One author has been designated as the corresponding author with contact details (e-mail address and full postal address) (see 'Title page' section for more information and an example)

2.	CRediT Contribution	Author will be asked to provide CRediT Contributions as well as their degree of contribution at the time of the original submission. CRediT Contribution is a high-level classification of the diverse roles performed in the work leading to a published research output in the sciences. Its purpose to provide transparency in contributions to scholarly published work, to enable improved systems of attribution, credit, and accountability.
3.	Abstract	Must not exceed 250 words. Relevant keywords (up to five keywords) must be included at the end of the abstract. (see the 'Abstract' section for more details)
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Additional considerations the author should confirm before submission:

1. Manuscript must be 'spell-checked', 'grammar-checked', and 'plagiarism-checked'.
2. All figures, tables, and references mentioned in the text should match the files provided.
3. Permission must be obtained for use of copyrighted material from other sources (including the internet).
4. Authors must provide conflicts of interest statement, even if there is no conflict of interests to declare.

Ethical Guidelines

Authors must acknowledge to the following ethical guidelines for publication and research.

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Experimentation involving animal subjects should be carried out in accordance with the guidelines laid down by the National Institute of Health (NIH) in the USA or with the European Communities Council Directive of 24 November 1986 (86/609/EEC) and in accordance with local laws and regulations. Editors reserve the right to reject papers if there is doubt as to whether appropriate procedures have been used.

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- NIH Clinical Trials Database
- EU Clinical Trials Register
- ISRCTN Registry

The clinical trial registration number and name of the trial register should be included in Materials and Methods of the manuscript. For epidemiological observational trials, authors of epidemiological human observations studies are required to review and submit a 'strengthening the reporting of observational studies in Epidemiology' (STROBE) checklist and statement. Compliance with this must be detailed in Materials and Methods.

D. Systematic Review

The abstract and main body of the systematic review should be reported using the PRISMA for Abstract and PRISMA guidelines respectively. Authors submitting a systematic review should register the protocol in one of the readily-accessible sources/databases at the time of project inception and not retrospectively (e.g. PROSPERO database, OSF registries). The protocol registration number, name of the database or journal reference should be provided at the submission stage in Materials and Methods. A PRISMA checklist and flow diagram (as a Figure) should also be included in the submission material.

E. Conflicts of Interest

All authors must disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work. Potential sources of conflict of interest include (but are not limited to) patent or stock ownership, membership of a company board of directors, membership of an advisory board or committee for a company, and consultancy for or receipt of speaker's fees from a company. If there are no interests to declare, please state 'The authors declare no conflict of interest'. Authors must disclose any interests in the section after acknowledgments.

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Submission of an article implies that the work described has not been published previously (except in the form of an abstract, a published lecture or academic thesis), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright- holder. The conference proceedings are allowed to be part of the article if the contents do not exceed 70% of the article.

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Manuscript Preparation

All texts in the submitted manuscript are required to be inclusive language throughout that acknowledges diversity, conveys respect to all people, is sensitive to differences, and promotes equal opportunities. Authors should ensure that writing is free from bias, for instance by using 'he or she', 'his/her' instead of 'he' or 'his', and by making use of job titles that are free of stereotyping (for instance by using 'chairperson' instead of 'chairman' and 'flight attendant' instead of 'stewardess'). Articles should make no assumptions about the beliefs or commitments of any reader, should contain nothing which might imply that one individual is superior to another on the grounds of race, sex, religion, culture, or any other characteristic.

A. Title page

The title page will remain separate from the manuscript throughout the peer review process and will not be sent to the reviewers. It should include these following details:

- Title should be concise, information-retrieval, and not exceed 30 words. Please avoid abbreviations and formulae where possible.
- Author names and affiliations. Please clearly indicate the given name(s) and family name(s) of each author are accurately spelled. Present the authors' affiliation addresses (where the actual work was done) below the names. Indicate all affiliations with a lower-case superscript number immediately after the author's name and in front of the appropriate address. Provide the full postal address of each affiliation, including the country name and the e-mail address of each author.
- Corresponding author will handle correspondence at all stages of refereeing and publication, also post-publication. This responsibility includes answering any future queries about Methodology and Materials. Please ensure that the e-mail address and contact details given are kept up to date by the corresponding author.

B. Abstract

Abstract must not exceed 250 words with concise and informative explanations about the article. Authors must prepare an abstract separately from the main manuscript using Microsoft Word processing software (.doc or .docx). Please avoid references and uncommon abbreviations, but if essential, abbreviations must be defined at their first mention in the abstract itself. Abstract structure of the original articles must consist of ‘Objectives, Methods, Results, and Conclusions’.

Abstract of other types of submitted articles should be summarized in one paragraph. Up to five keywords relevant to the articles must be provided and arranged in alphabetical order.

C. Manuscript

Oral Sciences Reports adheres to a double-blinded review. The main body of the paper (including the references, figures, tables and any acknowledgements) must not include any identifying information, such as the authors' names. The layout of the manuscript must be as simple as possible with double-spaced, single column format with Sans Serif font and uploaded as an editable Microsoft Word processing file (.doc or .docx). Complex codes or hyphenate options must be avoided, but the emphatic options such as bold face, italics, subscripts, and superscripts, etc. are encouraged.

1. Original article

• *Introduction* should include literature reviews of previous studies, research questions, and the rationale for conducting the study. The Introduction should not be too long and should be easy to read and understand while avoiding a detailed literature survey or a summary of the results.

• *Methods* should provide sufficient details in a logical sequence to allow the work to be reproduced by an independent researcher. Methods that are already published should be summarized and indicated by a reference. If quoting directly from a previously published method, use quotation marks and cite the source. Any modifications to existing methods should also be described.

• *Results* should show the data gained from the study's design in text, tables and/or illustrations, as appropriate, and be clear and concise.

• *Discussion* is criticism, explanation, and defense of the results from the standpoint of the author, and comparison with other peoples' reports. The discussion can include criticism of materials, methods and study results, problems, and difficulties, pointing out the benefits of adoption and providing feedback where appropriate. Discussions should explore the significance of the results of the work, not repeat them. Avoid extensive citations and discussion of published literature.

• *Conclusions* refers to a summary of the study or research results.

• *Acknowledgments:* Please specify contributors to the article other than the authors accredited. Please also include specifications of the source of funding for the study.

Formatting of funding source:

This work was supported by the 1st organization name [grant numbers xxxx]; the 2nd organization name [grant number yyyy]; and the 3rd organization name [grant number zzzz].

If no funding has been provided for the research, please include the following sentence:

This research did not receive any specific grant or funding from funding agencies in the public, commercial, or not-for-profit sectors.

• *References* should be confined to documents relating to the author's article or study. The number should not exceed 80, placed in order and using numbers which are superscripted and put in parentheses, starting with number 1 in the article and in reference document's name. (see 'References' section for more information regarding reference formatting)

2. Review articles should be divided into Introduction, Review and Conclusions. The Introduction section should be focused to place the subject matter in context and to justify the need for the review. The Review section should be divided into logical sub-sections in order to improve readability and enhance understanding. Search strategies must be described, and the use of state-of-the-art evidence-based systematic approaches is expected. The use of tabulated and illustrative material is encouraged. The Conclusion section should reach clear conclusions and/or recommendations on the basis of the evidence presented.

3. Systematic review

• Introduction should be focused to place the subject matter in context and to justify the need for the review.

• Methods should be divided into logical sub-sections in order to improve readability and enhance understanding (e.g. details of protocol registration, literature search process, inclusion/exclusion criteria, data extraction, quality assessment, outcome(s) of interest, data synthesis and statistical analysis, quality of evidence).

• Results should present in structured fashion (e.g. results of the search process, characteristics of the included studies, results of primary meta-analysis, additional analysis, publication bias, quality of evidence).

• Discussion should summarize the results, highlighting completeness and applicability of evidence, quality of evidence, agreements and disagreements with other studies or reviews, strength and limitations, implications for practice and research.

• Conclusion(s) should reach clear conclusions and/or recommendations on the basis of the evidence presented.

4. Case reports/series should be divided into Introduction, Case report, Discussion and Conclusions. They should be well illustrated with clinical images, radiographs and histologic figures and supporting tables where appropriate. However, all illustrations must be of the highest quality.

There are some necessary considerations which should be comprehended and consistent throughout the article:

1. Abbreviations: define abbreviations at their first occurrence in the article: in the abstract and in the main text after it. Please ensure consistency of abbreviations throughout the article.

2. Mathematical expressions: the numbers identifying mathematical expressions should be placed in parentheses after the equation, flush to the right margin; when referring to equations within text, use the following style: Eq. (5), Eqs. (3-10), [see Eq. (4)], etc.

3. Nomenclature: abbreviations and acronyms should be spelled out the first time they are used in the manuscript or spelled out in tables and figures (if necessary). Units of measure and time require no explanation. Dental nomenclature in the manuscript should be complete words, such as maxillary right central incisor. Numbering of teeth from pictures or tables should follow the FDI two-digit system.

4. Units: use the international system of units (SI). If other units are mentioned, please give their equivalent in SI.

5. Product identification: all products mentioned in the text should be identified with the name of the manufacturer, city, state, and country in parentheses after the first mention of the product, for example, The ceramic crown was cemented on dentin surface with resin cement (RelyX^{TM} U200, 3M ESPE, St. Paul, MN, USA)…

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Figures should be prepared and submitted separately from the main manuscript. Color artworks are encouraged at no additional charge. Regardless of the application used other than Microsoft Office, when the electronic artwork is finalized, please ‘save as’ or ‘export’ or convert the images to **EPS, TIFF, or JPEG format with the minimum resolution of 300 dpi.** Keep the artwork in uniform lettering, sizing, and similar fonts. Please do not submit graphics that are too low in resolution or disproportionately large for the content. Authors must submit each illustration as a separate file.

Please ensure that each illustration has a caption according to their sequence in the text and supply captions separately in editable Microsoft Word processing file (.doc or .docx), not attached to the figure. A caption should comprise a brief title (not on the figure itself) and a description of the illustration. Keep text in the illustrations themselves to a minimum but explain all symbols and abbreviations used.

E. Tables

Please submit tables as editable Microsoft Word processing files (.doc or .docx), not as images, and avoid using vertical rules and shading in table cells. Each table should be placed on a separate page, not next to the relevant text in the article. Number tables consecutively in accordance with their appearance in the text and place any table notes below the table body while ensuring that the data presented in them does not duplicate results described elsewhere in the article.

F. References

Citation in text

Any citations in the text should be placed in order and using numbers which are superscripted and put in parentheses. Please ensure that all citations are also present in the reference list consecutively in accordance with their appearance in the text.

Reference style

All references should be brought together at the end of the paper consecutively in accordance with their appearance in the text and should be in the Vancouver reference format. Please follow these examples of correct reference format below:

1. Journal article

1.1. One to six authors

Author(s) – Family name and initials. Title of article. Abbreviated journal title. Publication year;volume (issue):pages.

Example:

Parvez GM. Pharmacological activities of mango (Mangifera Indica): A review. J Pharmacognosy Phytother. 2016;5(3): 1-7.

Or

Choi YS, Cho IH. An effect of immediate dentin sealing on the shear bond strength of resin cement to porcelain restoration. J Adv Prosthodont. 2010;2(2):39-45.

Or

Firmino RT, Ferreira FM, Martins CC, Granville-Garcia AF, Fraiz FC, Paiva SM. Is parental oral health literacy a predictor of children's oral health outcomes? Systematic review of the literature. Int J Paediatr Dent. 2018;28(5):459-71.

1.2. More than six authors

Author(s) – Family name and initials of the first six authors, et al. Title of article. Abbreviated journal title. Publication year;volume(issue):pages.

Example:

Vera J, Siqueira Jr JF, Ricucci D, Loghin S, Fernández N, Flores B, et al. One-versus two-visit endodontic treatment of teeth with apical periodontitis: a histobacteriologic study. J Endod. 2012;38(8):1040-52.

1.3. Article in press

Authors separated by commas – Family name and initials. Title of article. Abbreviated journal title in italics. Forthcoming - year of expected publication.

Example:

Cho HJ, Shin MS, Song Y, Park SK, Park SM, Kim HD. Severe periodontal disease increases acute myocardial infarction and stroke: a 10-year retrospective follow-up study. J Dent Res. Forthcoming 2021.

2. Books

2.1. Book with author (s)

Author(s) – Family name and initials (no more than 2 initials with no spaces between initials)– Multiple authors separated by a comma. After the 6th author add - "et al". Title of book. Edition of book if later than 1st ed. Place of publication: Publisher name; Year of publication.

Example:

Sherwood IA. Essentials of operative dentistry. Suffolk: Boydell & Brewer Ltd; 2010.

Or

Abrahams PH, Boon JM, Spratt JD. McMinn's clinical atlas of human anatomy. 6th edition. Amsterdam: Elsevier Health Sciences; 2008.

2.2. Book with no author

Title of book. Edition of book if later than 1st ed. Place of publication: Publisher name; Year of publication.

Note: Do not use anonymous. Please begin a reference with the title of the book if there is no person or organization identified as the author and no editors or translators are given.

Example:

A guide for women with early breast cancer. Sydney: National Breast Cancer; 2003.

2.3. Chapter in a book

Author(s) of chapter - Family name and initials, Title of chapter. In: Editor(s) of book - Family name and initials, editors. Title of book. edition (if not first). Place of publication: Publisher name; Year of publication. p. [page numbers of chapter].

Example:

Rowlands TE, Haine LS. Acute limb ischaemia. In: Donnelly R, London NJM, editors. ABC of arterial and venous disease. 2nd ed. West Sussex: Blackwell Publishing; 2009. p. 123-140.

3. Thesis/dissertation

3.1. Thesis in print

Author - family name followed by initials. Thesis title [type of thesis]. Place of publication: Publisher; Year.

Example:

Kay JG. Intracellular cytokine trafficking and phagocytosis in macrophages [dissertation]. St Lucia, Qld: University of Queensland; 2007.

3.2. Thesis retrieved from full text database or internet

Author - family named followed by initials. Thesis title [type of thesis/dissertation on the Internet]. Place of publication: Publisher; Year [cited date – year month day]. Available from: URL

Example:

Pahl KM. Preventing anxiety and promoting social and emotional strength in early childhood: an investigation of risk factors [dissertation on the Internet]. St Lucia, Qld: University of Queensland; 2009 [cited 2017 Nov 22]. Available from: https://espace.library.uq.edu.au/view/UQ:178027

4. Webpage

4.1. Webpage with author

Author/organization's name. Title of the page [Internet]. Place of publication: Publisher's name; Publication date or year [updated date - year month day; cited date - year month day]. Available from: URL

Example:

American Dental Association. COVID-19 and Oral Health Conditions [Internet]. Chicago: American Dental Association; 2021 Feb 12 [updated 2021 Feb 12; cited 2021 Jun 24]. Available from: https://www.ada.org/en/press-room/news-releases/2021-archives/february/covid-19-and-oral-health-conditions

4.2. Webpage with no authors

Title [Internet]. Place of publication (if available): Publisher's name (if available); Publication date or year [updated date (if available); cited date]. Available from: URL

Example:

Dentistry and ADHD [Internet]. 2019 Jan 15 [updated 2019 Jan 15; cited 2020 Apr 8]. Available from: https://snoozedentistry.net/blog/dentistry-and-adhd/

4.3. Image on a webpage

Author/organization. Title [image on the Internet]. Place of publication: Publisher's name; Publication date or year [updated date; cited date]. Available from: URL

Note: If the image does not have a title - give the image a meaningful title in square brackets.

Example:

Poticny DJ. An Implant-Supported Denture Offers a Number of Advantages [image on the Internet]. Texas: Office of Dan Poticny; 2018 Nov 21 [updated 2018 Nov 21; cited 2019 Aug 30]. Available from: https://www.dfwsmiledoc.com/blog/post/an-implant-supported-denture-offers-a-number-of-advantages.html

5. Government publications/reports

5.1. Reports and other government publications

Author(s). Title of report. Place of publication: Publisher; Date of publication – year month (if applicable). Total number of pages (if applicable eg. 24 p.) Report No.: (if applicable)

Example:

Australian Institute of Health and Welfare. Oral health and dental care in Australia: key facts and figures trends 2014. Canberra: AIWH; 2014.

5.2. Government reports available online

Author(s). Title of report. Report No.: (if applicable). [Internet]. Place of publication: Publisher or Institution; Publication date or year [updated date - year month day; cited date - year month day]. Available from: URL

Example:

World Health Organization. WHO mortality database [Internet]. Geneva: World Health Organization; 2019 Dec 31 [updated 2019 Dec 31; cited 2021 Mar 29]. Available from: https://www.who.int/data/mortality/country-profile

6. Tables/Figures/Appendices

Follow the format of book, journal or website in which you found the table/figure/appendix followed by: table/figure/image/appendix number of original source, Title of table/figure/appendix from original source; p. Page number of table/figure/appendix from original source.

Note: each reference to a different table/figure within the same document requires a separate entry in the Reference list. Please provide permission documents from the original sources.

Example:

Smith J, Lipsitch M, Almond JW. Vaccine production, distribution, access, and uptake. Lancet 2011;378(9789):428-438. Table 1, Examples of vaccine classes and associated industrial challenges; p. 429.

7. Journal abbreviation source

Journal names should be abbreviated according to the Web of Science - Journal Title Abbreviations.

Peer-review Process

Oral Sciences Reports follows a double anonymized review process. Each manuscript will be assigned to at least three expertises for consideration. The identities of both reviewers and authors are concealed from each other throughout the review to limit reviewer bias. To facilitate this, please ensure that the manuscript keeps anonymity before submission such as affiliation, author's gender, country or city of origin, academic status, or previous publication history. Our peer review process is confidential and identities of reviewers are not released. Letters and technical comments are sent to the authors of the manuscript on which they comment for response or refutation, but otherwise are treated in the same way as other contributions with respect to confidentiality.

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Review Article

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How Do CAD/CAM Hybrid Materials Perform Under Cyclic Fatigue and High Occlusal Loads? A Mini-review Article

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Abstract

The rapid advancement of computer-aided design and manufacturing (CAD/CAM) technology has transformed restorative dentistry, offering materials that combine esthetic quality with mechanical durability for indirect restorations. This mini-review evaluates the fatigue resistance and fracture behavior of CAD/CAM hybrid materials, particularly under cyclic loading and high occlusal forces. The analysis encompasses both subtractive (milling) and additive (3D printing) manufacturing methods, emphasizing each method's advantages and limitations. Hybrid materials, such as polymer-infiltrated ceramic networks (e.g., Vita Enamic®), high-density resin composites (e.g., Cerasmart®), and laser-sintered composites (e.g., Edelweiss CAD/CAM BLOCK®), are discussed in terms of their mechanical properties, including flexural strength, hardness, and resilience under fatigue.

Data from *in vitro* studies indicate that hybrid materials maintain high durability under static and cyclic fatigue conditions when fabricated at optimal thicknesses (1.0-1.5 mm), withstanding forces well beyond typical masticatory loads. These properties make hybrid ceramics suitable for minimally invasive restorations that preserve tooth structure and minimize wear on opposing dentition. However, thinner restorations (≤0.8 mm) demonstrate increased susceptibility to fracture under high occlusal forces, particularly in patients with bruxism. The review underscores the need for standardized fatigue testing protocols that mimic clinical conditions more accurately to improve predictive validity.

Keywords: CAD/CAM, cyclic fatigue, fracture resistance, hybrid materials

Introduction

Computer-aided design and manufacturing (CAD/CAM) technology is extensively used in dentistry for the fabrication of indirect fixed prostheses, including veneers, onlays, crowns, bridges, and implant-supported restorations. This technology encompasses both subtractive (milling) and additive (3D printing) manufacturing methods. Subtractive milling, known for reducing fabrication time, can lead to material waste, tool wear, and marginal chipping, particularly in thin restorations.[1] In contrast, 3D printing builds models layer by layer, minimizing waste and enabling the creation of intricate details such as undercuts. However, both methods require substantial investments in equipment, specialized software, and training, alongside strategic material selection to balance strength, esthetics, biocompatibility, and cost.[1] Milling machines are categorized into chairside and laboratory systems, each employing four- or five-axis milling strategies based on material complexity and requirements. Chairside milling facilitates in-office fabrication after scanning the patient's teeth, eliminating the need for temporization and additional appointments, while delivering highly customized restorations tailored to the patient's anatomy and esthetics. Laboratory milling, by contrast, utilizes more advanced equipment for fabricating complex restorations or using materials unsuitable for chairside processes.[2] Additive manufacturing (3D printing) in dentistry offers versatility, with key techniques including powder bed fusion (PBF), fused deposition modeling (FDM), and light/laser curing processes like stereolithography (SLA), digital light processing (DLP), and photo jet (PJ). These methods predominantly use tooth-colored ceramic and resin materials, enhancing the esthetics and functionality of the final restorations.[3]

CAD/CAM esthetic dental materials include glass ceramics, resin composites, and hybrid ceramics. Glass ceramics are highly valued for their strength, hardness, biocompatibility, and color stability. Among these, silica-based ceramics are the most common, while polycrystalline ceramics often incorporate zirconium for increased durability.[2] However, glass ceramics can be brittle, making them more susceptible to chipping or fracture under heavy occlusal forces or during milling. Their limited flexural strength can also restrict their use in restorations subjected to high stress. Resin composites, composed of an organic resin matrix and inorganic fillers, offer flexibility but still face challenges with color stability and long-term durability, despite improvements in filler technology. To overcome these limitations, hybrid ceramics have been developed, combining the properties of both ceramics and resin composites.[3-5] CAD/CAM resin matrix ceramics address this gap by blending the reparability and low abrasiveness of composites with the high flexural strength and low elastic modulus of ceramics. This combination enables stress absorption similar to dentin, reducing abrasion on opposing teeth and enhancing restoration longevity.[3-5] Hybrid ceramics also offer practical advantages, such as shorter milling times, extending the lifespan of milling tools. Additionally, they do not require post-milling processes like sintering or crystallization, thereby streamlining the fabrication process and increasing workflow efficiency.[6]

One example of a hybrid material is the polymer-infiltrated ceramic network (PICN) known as Vita Enamic® (Vita Zahnfabrik, Germany). This material consists of an 86% sintered ceramic matrix infiltrated with 14% polymer by weight, providing a combination of ceramic strength and polymer flexibility. Vita Enamic® is widely used in minimally invasive restorations, including veneers, crowns, inlays, onlays, and implant-supported crowns. Studies highlight its favorable mechanical properties, making it particularly suitable for clinical applications that require high wear resistance and minimal tooth reduction. Another prominent hybrid material is Cerasmart® (GC Corporation, Japan), a high-density resin composite containing 71% alumina-barium-silicate nanoparticles. Cerasmart® has an elastic modulus of 10.0 GPa and a Vickers hardness of 64.1 HV, which is lower than Vita Enamic® (28.5 GPa / 189.8 HV).[7,8] Despite its comparatively lower hardness, Cerasmart® is favored for its high marginal integrity and strength. A study by Suksuphan *et al.,* confirmed its excellent marginal adaptation and fracture resistance, supporting its clinical reliability.[4] Edelweiss CAD/CAM BLOCK® (Edelweiss Dentistry Products, Austria) is another innovative hybrid material, composed of 82% filler by weight, including barium dental glass within a Bis-GMA hybrid matrix. Created through a patented laser sintering and vitrification process, this material exhibits a flexural strength of 200 MPa, a compressive strength of 550 GPa, a flexural modulus of 20 GPa, and a surface hardness of 100 HV. Edelweiss® also contains zinc oxide nanoparticles and fluoride, adding antibacterial

properties.[9] While these materials are predominantly fabricated through milling, new options like VaseoSmile Crown plus® are emerging. VaseoSmile Crown plus® is a pioneering 3D-printed hybrid material that combines silanized dental glass, methyl benzoylformate, phosphine oxide, and 30-50% inorganic filler with particles of 0.7 µm, expanding the potential applications of hybrid dental materials.[4]

Fracture analysis and fatigue testing of hybrid dental materials

Preserving tooth structure and ensuring adequate thickness in restorative materials are essential for the longevity and durability of dental restorations. Normal masticatory forces generally range between 9 and 180 N, with an average force of less than 70 N applied for 0.25-0.33 seconds per cycle.[10,11] However, studies indicate that bruxism patients can exert much higher forces, ranging from 777.7±78.7 N to 1692 N.[12] Observations over three nights with 10 bruxism patients revealed an average nocturnal bite force of 220.6±127.5 N, sustained for an average of 7.1±5.3 seconds.[13] To withstand such forces, manufacturers recommend specific minimum thicknesses for hybrid materials: 1.5 mm for Cerasmart® and Edelweiss® and 1.0 mm for Vita Enamic®.[4,9] Mohamed Alghauli *et al.,* categorized restorative materials by thickness as ultrathin (0.3-0.6 mm), thin (0.5-0.8 mm), and thick (0.8-1.5 mm), offering additional guidance on appropriate application.[14]

Research by Suksuphan *et al.* examined the fracture resistance of Cerasmart®, Vita Enamic®, and Varseosmile® crowns at thicknesses of 0.8, 1.0, and 1.5 mm. Their findings showed that Cerasmart® crowns could withstand forces up to 2000 N, whereas Vita Enamic® crowns fractured at 0.8 mm. Varseosmile® crowns fractured at a slightly lower force of 1480.3±226.1 N at 0.8 mm.[4] Similarly, Zamzam *et al.,* evaluated the failure behavior of 1.5 mm occlusal veneers made from Vita Enamic®, IPS e.max CAD®, and Bruxzir® using Panavia F2.0® cement. Bruxzir® demonstrated the highest failure load (843.1±141.5 N), followed by IPS e.max CAD® (493.21±102.24 N) and Vita Enamic® (499.6±123.1 N), aligning with finite element analysis predictions.[15]

Schlenz *et al.,* studied fatigue damage in 1.5 mm monolithic CAD/CAM hybrid crowns, including composites like Lava Ultimate®, Cerasmart®, and Brilliant Crios®, as well as PICN (Vita Enamic®) and LDS ceramics (IPS e.max CAD®). Under high masticatory forces (50-500 N) at 2 Hz over 1 million cycles, all crowns survived fatigue damage in occlusal contact areas without catastrophic failure. PICN and LDS ceramics exhibited the largest damage-free areas, especially when light-cured luting cement was used.[16]

Velho *et al.,* investigated the fatigue behavior of Vita Enamic® and IPS e.max CAD® using step-stress loading with Multilink Automix® cement on dentin-like substrates. Specimens were tested at 20 and 2 Hz with a starting load of 200 N and step increments of 100 N for 10,000 cycles per step. Results showed no significant differences in fatigue load or failure cycles between Vita Enamic® (20 Hz: 1127 N, 102,667 cycles; 2 Hz: 1120 N, 102,000 cycles) and IPS e.max CAD® (20 Hz: 980 N, 88,000 cycles; 2 Hz: 900 N, 80,000 cycles).[17]

The clinical outcomes of hybrid dental materials

Oudkerk *et al.,* conducted a prospective clinical study over a period of 5 years, evaluating the intraoral wear of PICN CAD-CAM composite restorations used in severe tooth wear treatment through *ex vivo* 3D profilometry examinations. Despite the presence of clinical signs of bruxism, the PICN material demonstrates a low wear process, making it a suitable material for the One-step No-prep procedure. Restoration success and survival rates at 5 years were 90.62% and 99.48%, respectively.[18]

Conclusions

The limitations of this review. For instance, this review focuses solely on fracture strength, while other properties should also be considered when selecting materials for clinical use. Collectively, these studies indicate that CAD/CAM hybrid materials can endure forces exceeding normal masticatory loads (585-880 N).[19,20] These findings suggest that hybrid dental materials offer promising clinical durability, although fracture resistance may vary depending on the specific material and thickness. Clinically, CAD/CAM hybrid materials perform well under static and cyclic fatigue, particularly at optimal thicknesses (1.0-1.5 mm), making them suitable for minimally invasive restorations. They also preserve the enamel of opposing teeth, although they may wear slightly faster themselves.[21] However, thinner restorations (≤0.8

mm) carry a higher fracture risk under significant occlusal forces.

Accurate simulation of the oral environment is essential for fatigue testing to yield reliable predictions about long-term performance. *In vitro* studies must use models that replicate clinical conditions closely. Currently, limited research examines cyclic fatigue in CAD/CAM hybrid crowns at different thicknesses. Future clinical research should focus on developing guidelines for bruxism patients to enhance the durability and mechanical wear resistance of occlusal restorations, ultimately ensuring optimal patient outcomes.

References

1. Van Noort R. The future of dental devices is digital. Dent Mater. 2012;28(1):3-12.
2. Skorulska A, Piszko P, Rybak Z, Szymonowicz M, Dobrzyński M. Review on polymer, ceramic and composite materials for CAD/CAM indirect restorations in dentistry—application, mechanical characteristics and comparison. Materials (Basel). 2021;14(7):1592.
3. Tian Y, Chen C, Xu X, Wang J, Hou X, Li K, *et al.* A review of 3D printing in dentistry: technologies, affecting factors, and applications. Scanning. 2021;2021:9950131. doi: 10.1155/2021/9950131.
4. Suksuphan P, Krajangta N, Didron PP, Wasanapiarnpong T, Rakmanee T. Marginal adaptation and fracture resistance of milled and 3D-printed CAD/CAM hybrid dental crown materials with various occlusal thicknesses. J Prosthodont Res. 2024;68(2):326-35.
5. Garoushi S, Barlas D, Vallittu P, Uctasli M, Lassila L. Fracture behavior of short fiber-reinforced CAD/CAM inlay restorations after cyclic fatigue aging. Odontology. 2024;112(1):138-47.
6. Schlichting LH, Maia HP, Baratieri LN, Magne P. Novel-design ultra-thin CAD/CAM composite resin and ceramic occlusal veneers for the treatment of severe dental erosion. J Prosthet Dent. 2011;105(4):217-26.
7. Lawson NC, Bansal R, Burgess JO. Wear, strength, modulus and hardness of CAD/CAM restorative materials. Dent Mater. 2016;32(11):e275-e283.
8. Bajraktarova-Valjakova E, Korunoska-Stevkovska V, Kapusevska B, Gigovski N, Bajraktarova-Misevska C, Grozdanov A. Contemporary dental ceramic materials, a review: chemical composition, physical and mechanical properties, indications for use. Open Access Maced J Med Sci. 2018;6(9):1742-55.
9. Edelweiss-dentistry. Edelweiss-dentistry. Edelweiss CAD/CAM BLOCK: Instruction for use on Edelweiss-dentistry, Hoerbranz, Austria. 2021-12.
10. DeLong R, Douglas WH. An artificial oral environment for testing dental materials. IEEE Trans Biomed Eng. 1991;38(4):339-45.
11. Lan TH, Chen PH, Fok ASL, Chen YF. Contact fracture test of monolithic hybrid ceramics on different substrates for bruxism. Dent Mater. 2022;38(1):44-56.
12. Reddy SV, Kumar MP, Sravanthi D, Mohsin AH, Anuhya V. Bruxism: a literature review. J Int Oral Health. 2014;6(6):105-9.
13. Koyano K, Tsukiyama Y, Ichiki R, Kuwata T. Assessment of bruxism in the clinic. J Oral Rehabil. 2008;35(7):495-508.
14. Al-Akhali M, Kern M, Elsayed A, Samran A, Chaar MS. Influence of thermomechanical fatigue on the fracture strength of CAD-CAM-fabricated occlusal veneers. J Prosthet Dent. 2019;121(4):644-50.
15. Zamzam H, Olivares A, Fok A. Load capacity of occlusal veneers of different restorative CAD/CAM materials under lateral static loading. J Mech Behav Biomed Mater. 2021;115:104290.
16. Schlenz MA, Schmidt A, Rehmann P, Wöstmann B. Fatigue damage of monolithic posterior computer aided designed/computer aided manufactured crowns. J Prosthodont Res. 2019;63(3):368-73.
17. Velho HC, Dapieve KS, Pereira GKR, Fraga S, Valandro LF, Venturini AB. Accelerated loading frequency does not influence the fatigue behavior of polymer infiltrated ceramic network or lithium disilicate glass-ceramic restorations. J Mech Behav Biomed Mater. 2020;110:103905.
18. Oudkerk J, Herman R, Eldafrawy M, Wulfman C, Ernst M, Vanheusden A, *et al.* Intraoral wear of PICN CAD-CAM composite restorations used in severe tooth wear treatment: 5-year results of a prospective clinical study using 3D profilometry. Dent Mater. 2024;40(7):1056-63.
19. Alghauli M, Alqutaibi AY, Wille S, Kern M. Clinical outcomes and influence of material parameters on the behavior and survival rate of thin and ultrathin occlusal veneers: a systematic review. J Prosthodont Res. 2023;67(1):45-54.
20. Dietschi D, Devigus A. Prefabricated composite veneers: historical perspectives, indications and clinical application. Eur J Esthet Dent. 2011;6(2):178-87.
21. Baldi A, Carossa M, Comba A, Alovisi M, Femiano F, Pasqualini D, *et al.* Wear behaviour of polymer-infiltrated network ceramics, lithium disilicate and cubic zirconia against enamel in a bruxism-simulated scenario. Biomedicines. 2022;10(7):1682.

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Management of Flared Root Canal with Anatomical Post and Core Using Conventional and Digital Technique: A Literature Review

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Abstract

Endodontically treated teeth often requires internal retainers and cores to support the final restoration due to significant structural damage. Nevertheless, the discrepancy between the size of the root canal space and the diameter of the post is an important clinical consideration, especially in cases of flared or widened root canals. Even though cast metal post and cores can adapt well to remaining root structure, they present a high elastic modulus which can lead to irreparable root fractures. Conversely, bonding prefabricated glass-fiber posts to flared root canals results in thick resin cement layers, increasing the possibility of structural discontinuities and potentially creating a weak spot in the restoration.

Anatomic post is one of the techniques involving the reconstruction of flared root canals by lining glass-fiber posts with resin composite to match the shape of the flared post space. However, multiple interfaces are created when several materials are used.

The computer-aided design/computer-aided manufacture (CAD/CAM) process can be applied to the production of individually, anatomically fitted, and monolithic posts. Eliminating the need for multiple materials and reducing the number of interfaces in the cemented structure. Both of these technique approaches are highly effective in reducing the amount of luting cement required, enhancing mechanical properties of the restoration and reducing chances of irreparable fracture.

The aim of this literature review is to provide general information, methods for making post and core, mechanical properties, and discuss the efficacy of anatomic fiber post and CAD/CAM customized post and core in flared canals.

Keywords: anatomical post, CAD/CAM post and core, flared root canal

Introduction

Root canal treated teeth often have significant loss of tooth structure, increasing the risk of fracture. Therefore, they are commonly restored with indirect restoration to strengthen the structure, such as crowns and onlays. In some occasions, root canal treated teeth may have flared root canals, which tend to have less strength than normal teeth. Teeth with slightly flared root canals have a higher percentage of circumference in the cervical area larger than the largest prefabricated post, which is around 25-50 percent.[1] Whereas teeth with very flared root canals have more circumference in the cervical area than the largest size of prefabricated post, which is around 50 percent or more. The causes of this flared root canal can result from several factors such as tooth decay, childhood accidents[2], excessive post preparation[3], improperly root canal treatment[4], abnormalities in growth such as tooth germination, and fused root canals.[4] The amount of remaining tooth structure affects the strength of the tooth.[5] Minimal remaining root canal dentin increases the risk of fracture, even with normal chewing forces, therefore, requires additional treatment such as post and core.[6]

Using only a prefabricated post for a flared shape of the root canal, often results in a thick cement layer, which is weak and typically develops air bubbles. This creates a weak point in the restorative material due to stress from shrinkage during polymerization, leading to potential fracture lines and reduced bond strength of the post to the root canal.[7]

Therefore, various methods have been proposed to treat teeth with flared root canals. One of these methods includes anatomical post, which was introduced by Grandini and colleagues in 2003.[8] This method involves using resin composite material to reinforce a glass fiber post, mimicking the shape of the root canal. This approach can reduce the amount of cement and minimize shrinkage during polymerization compared to using cement alone.[6,8-12] Additionally, other methods were proposed which include using accessory posts to fill the space between the main post and the root canal wall.[5,6,12] However, research suggests that using accessory posts does not improve retention in flared root canals and may still lead to air bubbles in the cement. Another method involves intraradicular reinforcement by using resin composite to reinforce the root canal wall.[13] This method increases the thickness of the wall, but it can be challenging to achieve complete polymerization, especially at the root apex.[4,10]

When comparing the fracture resistance of tooth with flared root canals restored with different methods, it has been found that anatomical posts, accessory posts, and intraradicular reinforcement did not significantly differ in fracture resistance.[6,7] However, some studies have shown that anatomical posts provide higher fracture resistance compared to the use of accessory posts.[5,12] Regarding bond strength, anatomical posts, accessory posts, and intraradicular reinforcement did not significantly differ statistically, but they exhibited higher bond strength compared to using prefabricated posts alone.[7] Additionally, when studying stress distribution in teeth with flared root canals restored using various methods, it was found that anatomical posts distributes forces within the post and generates less stress around the root compared to reconstruction using accessory posts and intraradicular rehabilitation.[14] Therefore, considering the mechanical properties, restoring flared canal with anatomical posts represents another interesting option.

Various methods have been employed to fabricate anatomical posts and cores, including the use of digital dentistry. Therefore, the objective of this study is to explore data and methods for using anatomical posts in various situations and to compare the properties of anatomical posts in each types of fabrication.

Materials and Methods

The PubMed (MEDLINE) database was the main resource for gathering the most relevant and current information on anatomical posts and CAD/CAM posts. The search focused on studies published in English from 2000, when research on anatomical posts began, through 2023. Supplementary research was gathered via Google Scholar and targeted searches. The most significant article, along with selected studies, is included in the references.

Literature review

Conventional fabrication of anatomical post and core

There are two methods to fabricate anatomical posts and cores using fiber-reinforced prefabricated posts: the direct technique and the indirect technique.

Direct technique

After removing the gutta percha to prepare the space for the post according to the planned length, a selected prefabricated post is tried in. Then, the prefabricated post is removed, cleaned, and the surface is prepared by applying a silane coupling agent, left for 30 seconds, blown dry, and then an adhesive is applied and light-cured for 20 seconds.

A water-soluble lubricating agent is applied in the root canal to prevent resin composite from adhering to the canal walls. Packable resin composite is then molded around the prefabricated post, and the post is inserted into the root canal. Light curing is done for 10 seconds to initiate preliminary resin composite curing. After this, the post with the resin composite base is removed from the root canal, and a complete curing is achieved through additional curing. Resin composite is then incrementally added layer by layer until the entire length of the post is filled. Finally, the post is shaped appropriately, and additional light curing is performed.

After obtaining the anatomical post, the surface of the post is prepared by applying 37% phosphoric acid for 30 seconds, followed by rinsing with water and drying with air. Next, an adhesive is applied, and then cement is placed into the root canal. Once the post is inserted, excess cement is removed using a small micro brush. After the anatomical post is securely placed, shaping of the core can be performed to prepare for the subsequent crown restoration (Figures 1 and 2).[15] Rubber dam application is advisable for this technique to reduce chance of contamination. However, due to specific condition of the patient a rubber dam was not used in this patient.

Indirect technique

An indirect fabrication technique of anatomical post is very similar to direct technique. However, the procedure is done on master model which comes from root canal impression (Figure 3). When compare between the two techniques it was found that direct technique can reduce laboratory process but has the disadvantages of a risk of resin composite locked in the root canal. On the other hand, the indirect technique can reduce chair time, improve accuracy, and decrease the risk of contamination.[5] Both methods of fabricating anatomical posts result in fracture resistance close to that of metal posts and cores, making them effective alternatives for restoring teeth with flared root canals.[5] However, the anatomical posts using resin composite with glass fiber reinforcement often leads to significant material interfaces due to the use of multiple materials. This method involves several fabrication steps and requires the skills of dentists or dental technicians to ensure that the final piece fits well within the root canal, which may affect long-term success.[7]

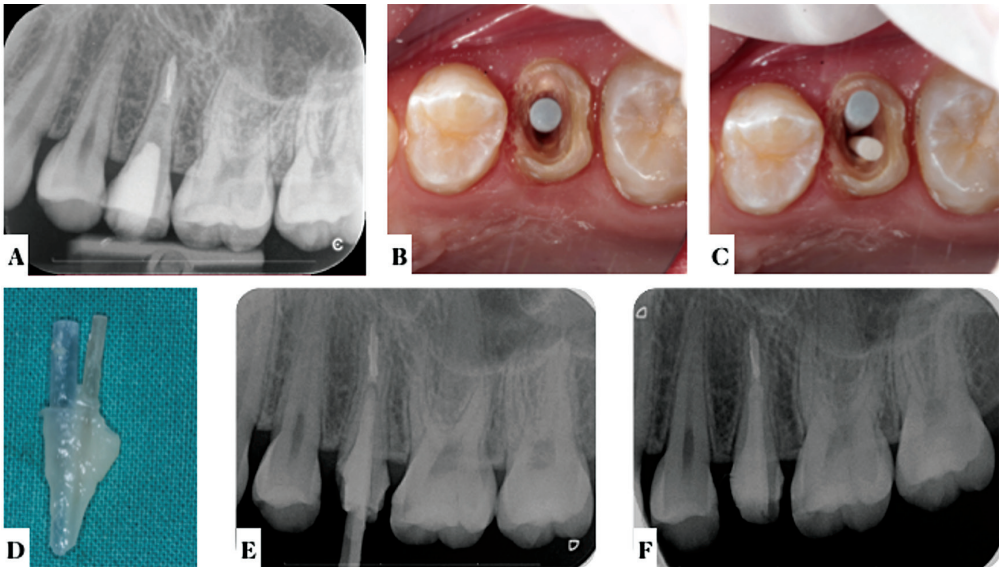

Figure 1: Clinical case for using direct technique to fabricate anatomical post and core. (A), Pre-operative radiograph: (B), Largest prefabricated post was tried-in: (C), A smaller prefabricated post was used as an additional post: (D), Composite resin was applied onto the posts: (E), Radiograph of pre-cementation of anatomical post: (F), Post-operative radiograph.

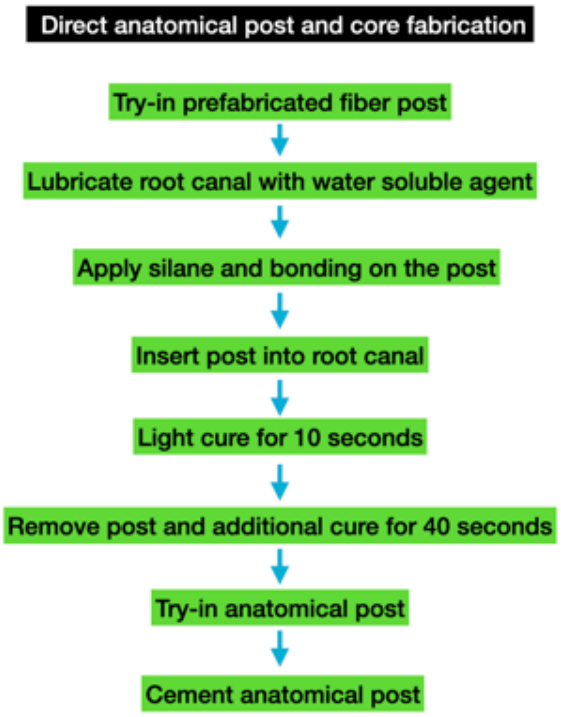

Figure 2: Summary of clinical workflow for direct anatomical post and core fabrication.

Digital fabrication technique for anatomical post and core

The use of computer-aided design and manufacturing in dentistry is another effective option for treating teeth with flared root canals due to its ability to create customized root canal models. This allows the post to fit well and adapt to the root canal. Additionally, using a single material to manufacture post and core reduces material contact surfaces and minimizes shrinkage due to polymerization.[16] CAD/CAM technology enhances the adaptation of the dental post to the root canal and reduces the thickness of the cement layer.[17] Other advantages of CAD/CAM systems include producing precise pieces, reducing errors from human work that may lead to mechanical failures, and the ability to use various types of materials.[18]

There are two ways of using CAD/CAM to fabricate anatomical posts which are fully digital and half digital.[19]

Fully digital technique

Fully digital technique involves using an intraoral scanner to scan the prepared root canal. After removing gutta percha to prepare the space for the post as planned, the intraoral scanner captures images of the coronal structure and the prepared root canal. The system processes these scans into a 3D image, which is then used for computer-aided design to design the post and core. Subsequently, the designed post and core are manufactured using milling or 3D printing machine. Once the post is fabricated, it is tried in the root canal. After fitting, the surface of the post and core is cleaned and prepared based on the chosen material. Adhesive is applied in the root canal, on the post, and the core. Cement is injected and cured according to the manufacturer's instructions. Finally, the core is shaped for subsequent crown placement (Figures 4 and 5).[20] Similar to direct anatomical post technique, rubber dam application is recommended. However, it may interfere with the scanning process like in this particular case. Therefore, the rubber dam was removed and scanning process was repeated without a rubber dam.

An alternative to directly scanning of root canal is to use Scan post™ (3shape; Copenhaegen, Denmark). The Scan post has its extension into root canal and the scan region similar to scan body used for implant restorations. Once it is scanned the CAD software then calculates length and position of the root canal which is then

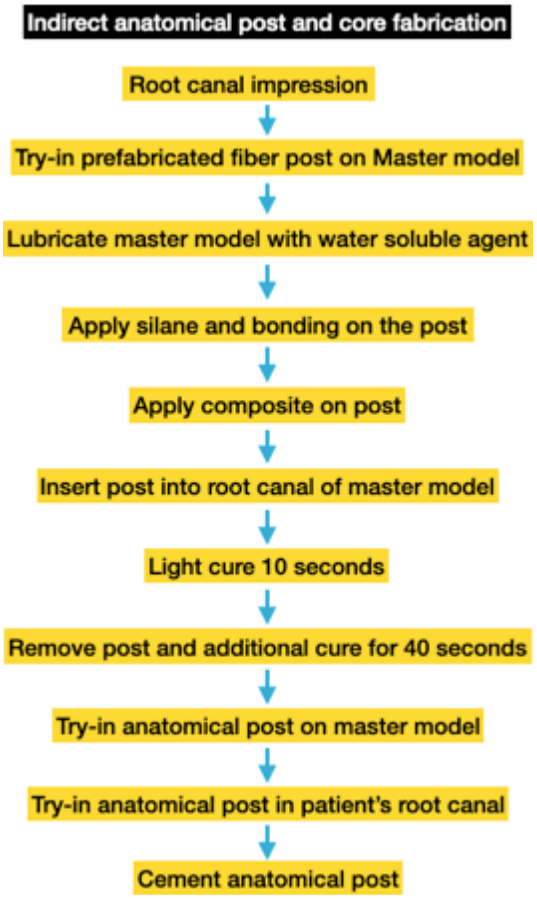

Figure 3: Summary of clinical workflow for indirect anatomical post and core fabrication.

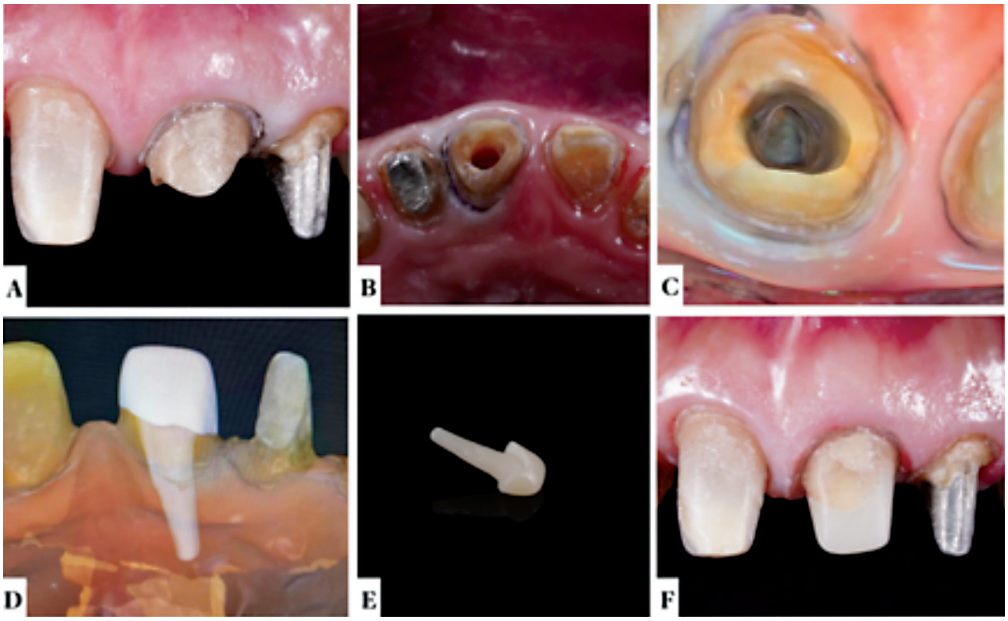

Figure 4: Clinical case for using fully digital technique to fabricate anatomical post and core. (A), Pre-operative anterior view of tooth: (B), Pre-operative occlusal view of tooth: (C), Occlusal view of 3D image from scanner: (D), Design of anatomical post: (E), Anatomical post milled from milling machine: (F), Anatomical post cemented into tooth.

used for designed. A study has shown that the accuracy of scanned root canal is similar with or without using Scan post™. Therefore, it can be used if direct scanning is prohibited.[21]

Half digital technique

Another alternative to direct root canal scanning is half digital technique which utilizes extraoral scanner to scan root canal impression[22], wax, resin or polyvinylsiloxane[23] pattern to fabricate definitive post and core.

Half digital technique involving root canal impression

For this technique, a root canal impression is performed using polyvinylsiloxane. After the impression is made, a scanner is used to digitize it. CAD software is then used to design the post and core accordingly. After that, the material of choice can be selected and fabricated using a milling machine or 3D printer (Figures 6 and 7).[24]

Half digital technique involving direct resin pattern fabrication

In this technique, wax, acrylic resin, or polyvinylsiloxane is used to replicate the shape of the root canal, and the core is also created using a resin pattern. An oral scanner is then used to scan the post and core. CAD software is subsequently used to design them, after which the desired material is selected and fabricated using a milling machine or 3D printer.[24]

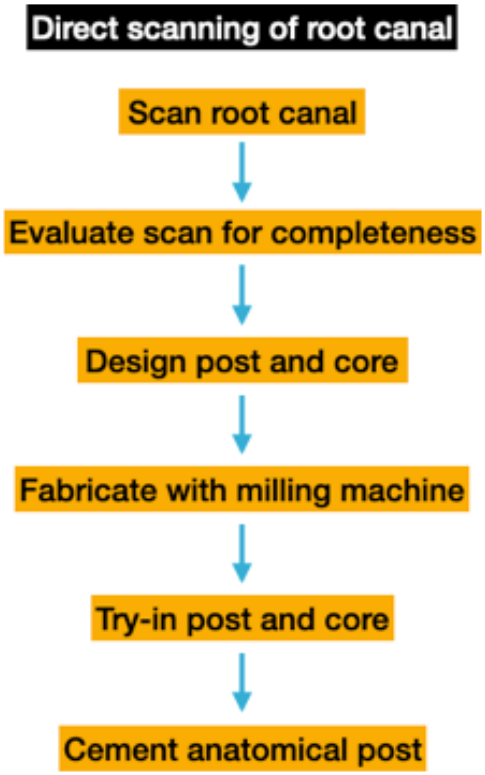

Figure 5: Summary of clinical workflow for fully digital technique.

When considering the advantages of fully digital technique, it is evident that factors causing inaccuracies in post and core fabrication, such as the use of impression materials, gypsum, or acrylic resin, can be eliminated.

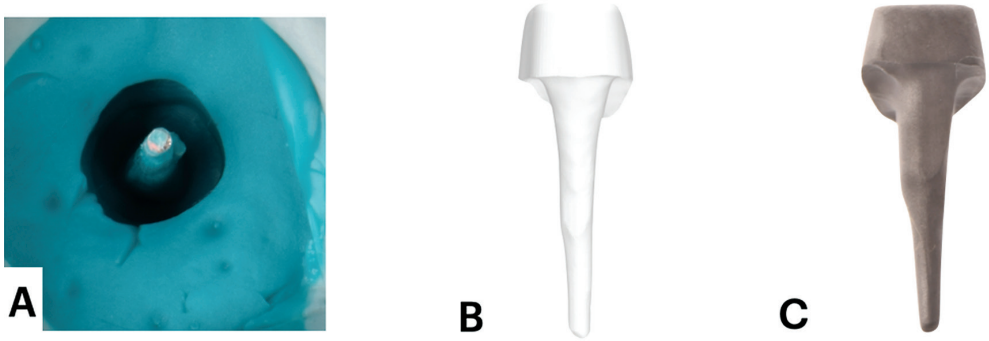

Figure 6: Clinical case for using half digital technique involving root canal impression to fabricate anatomical post and core. (A), Root canal impression: (B), STL file designed in software: (C), Post and core milled from a milling machine.

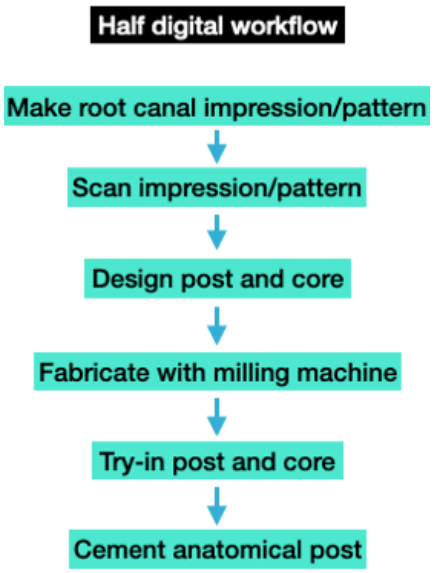

Figure 7: Summary of clinical workflow for half digital technique.

This approach also reduces chairside working time and minimizes laboratory procedures.[23] It was also shown in a study that using fully digital workflow to fabricate metal post and core was more accurate compared to half-digital workflow.[19] However, if the post space is particularly long, the intraoral scanner scan depth may not be enough. Additionally, in teeth with a small or narrow root canal opening, using the intraoral scanner directly may not capture all the details needed.[25] It was also found that the shape of the root canal affects the scanner's trueness. Specifically, if the post space is less than 14 millimeters in length and the root canal opening has a diameter of more than 2.2 millimeters, the intraoral scanner's accuracy was comparable to conventional impression techniques.[26] It is also recommended that, if root canal is longer than 10 mm, half digital technique or Scan post™ should be considered.[25]

Half digital technique involving polyvinylsiloxane pattern fabrication

In this technique, polyvinylsiloxane was directly injected into the root canal, and a rigid metal wire was inserted to form the post and core pattern. The core was created by overfilling the material on the prepared coronal part. Once the material had set, the excess was shaped into the ideal tooth preparation form using a diamond bur. The pattern was then removed, inspected for defects, and scanned. The scanned pattern was utilized to design and mill a wax post and core, which was subsequently cast into a custom metal post and core.[23]

The material used to fabricate post and core with milling machine includes metal, ceramic, and composite materials. However, the flared root canal is weaker, therefore, material with similar modulus of elasticity to dentin should be used.[27] It was found that composite material such as polymer infiltrated ceramic (PINC) had similar fracture resistance compared to metal and zirconia when cemented into root canal. It also showed more favorable failure mode as it was considered reparable.[28] Another composite material created for post and core is fiber glass reinforced composite (Fiber CAD post&core; Angelus, Londrina PR, Brazil) which has similar modulus of elasticity as dentin but offer high flexural strength due to its unidirectional glass fiber reinforcement. A study has shown that using fiber-reinforced composite fabricated with CAD/CAM has higher fracture resistance than conventional anatomical posts and cores when cemented into the root canal. It also demonstrated that the fracture resistance of this material is similar to that of custom metal posts and cores.[29] This result is also shown in another study where fiber-reinforced composite fabricated with CAD/CAM exhibited a higher fracture load than

glass-reinforced fiber posts and anatomical posts in flared root canals.[30] It has been concluded that anatomical posts fabricated using CAD/CAM systems have high precision and fit closely with the root canal, they provide high frictional retention. Additionally, the thin layer of cement allows the post to adhere well to the root canal. Furthermore, the fabrication of anatomical posts through milling creates a single piece (monolayer) for both the post and core, which enhances fracture resistance and improves stress distribution compared to traditional methods.[30]

The thickness of the cement layer is an important factor affecting bond strength, as cement has lower strength than fiber posts. The greater the thickness of the cement layer, the more it contributes to the volume of voids and gaps within the cement and the shrinkage that occurs during the polymerization process. As a result, the bond strength between root canal and post decrease.[30,31] The better adaptation of digitally fabricated post and core results in thinner cement layer thus increase bond strength. A study has shown that pushout bond strength of CAD/CAM fabricated glass fiber post was similar to anatomical post but significantly higher than prefabricated glass reinforced fiber post.[31] Moreover, the amount of cement gap found in CAD/CAM fabricated glass fiber post is less compared to anatomical post and prefabricated glass reinforced fiber post.

Conclusions

Digitally fabricated posts and cores showed promising results compared to conventional methods when restoring flared root canals. This technique can simplify difficult procedures by improving adaptation and bond strength between the root canal and anatomical post, thereby increasing fracture resistance.

References

1. Seckler IN dSBC, Kato AS, Pinheiro SL, Lima DA, de Souza DF. Impact of mechanical load of three post and core systems: CAD/CAM-fabricated glassfiber, prefabricated glassfiber customized with composite resin, and cast metal posts and cores. Cons Dent Endod J. 2020; 5(2):36-41.
2. Boksman L, Hepburn AB, Kogan E, Friedman M, de Rijk W. Fiber post techniques for anatomical root variations. Dent Today. 2011;30(5):104,106-11.
3. Gopal S, Irodi S, Mehta D, Subramanya S, Govindaraju VK. Fracture resistance of endodontically treated roots restored with fiber posts using different resin cements- an *in vitro* study. J Clin Diagn Res. 2017;11(2):Zc52-zc5.
4. Haji-Hassani N, Bakhshi M, Shahabi S. Frequency of iatrogenic errors through root canal treatment procedure in 1335 charts of dental patients. J Int Oral Health. 2015;7 (Suppl 1):14-7.
5. Tait CM, Ricketts DN, Higgins AJ. Weakened anterior roots–intraradicular rehabilitation. Br Dent J. 2005;198 (10):609-17.
6. Clavijo VG, Reis JM, Kabbach W, Silva AL, Oliveira Junior OB, Andrade MF. Fracture strength of flared bovine roots restored with different intraradicular posts. J Appl Oral Sci. 2009;17(6):574-8.
7. Bonfante G, Kaizer OB, Pegoraro LF, do Valle AL. Fracture strength of teeth with flared root canals restored with glass fibre posts. Int Dent J. 2007;57(3):153-60.
8. Gomes GM, Rezende EC, Gomes OM, Gomes JC, Loguercio AD, Reis A. Influence of the resin cement thickness on bond strength and gap formation of fiber posts bonded to root dentin. J Adhes Dent. 2014;16(1):71-8.
9. Grandini S, Sapio S, Simonetti M. Use of anatomic post and core for reconstructing an endodontically treated tooth: a case report. J Adhes Dent. 2003;5(3):243-7.
10. Macedo VC, Faria e Silva AL, Martins LR. Effect of cement type, relining procedure, and length of cementation on pull-out bond strength of fiber posts. J Endod. 2010;36(9):1543-6.
11. Gomes GM, Gomes OM, Gomes JC, Loguercio AD, Calixto AL, Reis A. Evaluation of different restorative techniques for filling flared root canals: fracture resistance and bond strength after mechanical fatigue. J Adhes Dent. 2014;16(3):267-76.
12. Barcellos RR, Correia DP, Farina AP, Mesquita MF, Ferraz CC, Cecchin D. Fracture resistance of endodontically treated teeth restored with intra-radicular post: the effects of post system and dentine thickness. J Biomech. 2013;46(15):2572-7.
13. Silva GR, Santos-Filho PC, Simamoto-Júnior PC, Martins LR, Mota AS, Soares CJ. Effect of post type and restorative techniques on the strain and fracture resistance of flared incisor roots. Braz Dent J. 2011;22(3):230-7.
14. Li Q, Xu B, Wang Y, Cai Y. Effects of auxiliary fiber posts on endodontically treated teeth with flared canals. Oper Dent. 2011;36(4):380-9.
15. Belli S, Eraslan Ö, Eraslan O, Eskitaşcıoğlu G. Effect of restoration technique on stress distribution in roots with flared canals: an FEA study. J Adhes Dent. 2014;16(2): 185-91.
16. Alto RV SG, Santos GO, Noronha J. Tips: customized glass fiber posts. Angelus. 2016:1-5.
17. Ruschel GH, Gomes É A, Silva-Sousa YT, Pinelli RGP, Sousa-Neto MD, Pereira GKR, Spazzin AO. Mechanical properties and superficial characterization of a milled CAD-CAM glass fiber post. J Mech Behav Biomed Mater. 2018;82:187-92.
18. Falcão Spina DR, da Costa RG, Correr GM, Rached RN.

Scanning of root canal impression for the fabrication of a resin CAD-CAM-customized post-and-core. J Prosthet Dent. 2018;120(2):242-5.
19. Ramos Júnior S, Felizardo KR, Guiraldo RD, Berger SB, Ramos NBP, Assis ACM de, *et al.* CAD-CAM endodontic posts: literature review. Res Soc Dev. 2021;10(1):1-7.
20. Hendi AR, Moharrami M, Siadat H, Hajmiragha H, Alikhasi M. The effect of conventional, half-digital, and full-digital fabrication techniques on the retention and apical gap of post and core restorations. J Prosthet Dent. 2019;121(2):364.
21. Libonati A, Di Taranto V, Gallusi G, Montemurro E, Campanella V. CAD/CAM customized glass fiber post and core with digital intraoral impression: a case report. Clin Cosmet Investig Dent. 2020;12:17-24.
22. Leven R, Schmidt A, Binder R, Kampschulte M, Vogler J, Wöstmann B, Schlenz MA. Accuracy of digital impression taking with intraoral scanners and fabrication of CAD/CAM posts and cores in a fully digital workflow. Materials (Basel). 2022;15(12):4199.
23. Piangsuk T, Dawson DV, El-Kerdani T, Lindquist TJ. The accuracy of post and core fabricated with digital technology. J Prosthodont. 2023;32(3):221-6.
24. Farah RI, Aloraini AS, Al-Haj Ali SN. Fabrication of custom post-and-core using a directly fabricated silicone pattern and digital workflow. J Prosthodont. 2020;29(7):631-5.
25. Piangsuk T, Henprasert P, Boonsiriphant P, Lindquist TJ. The accuracy comparison of 3D-printed post and core using castable resin and castable wax resin. J Prosthodont. 2023;32(6):540-5.
26. Al-Qarni FD. Customized post and cores fabricated with CAD/CAM technology: a literature review. Int J Gen Med. 2022;15:4771-9.
27. Elter B, Diker B, Tak Ö. The trueness of an intraoral scanner in scanning different post space depths. J Dent. 2022;127:104352.
28. Gehrcke V, de Oliviera M, Aarestrup F, do Prado M, de Lima CO, Campos CN. Fracture strength of flared root canals restored with different post systems. Eur Endod J. 2017;2(1):1-5.
29. Alkhatri R, Saleh ARM, Kheder W. Evaluating fracture resistance and failure modes of root filled teeth restored with CAD/CAM-fabricated post and core. Clin Cosmet Investig Dent. 2019;11:349-55.
30. Taques LV, Chidoski JC, Ávila BO, Jitumori RT, Gomes JC, Gomes GM. Evaluation of bond strength and fracture load of teeth with flared root canals restored with prefabricated, anatomical, and computer-aided design and computer-aided manufacturing fiber posts. Oper Dent. 2023;48(5):524-37.
31. Gama M, Balbinot GS, Ferreira GC, Mota EG, Leitune V, Collares FM. CAD/CAM milled glass fiber posts: adaptation and mechanical behavior in flared root canals. Oper Dent. 2021;46(4):438-47.

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Ion-releasing Resin Composites as Clear Aligner Attachments: Comparison of Caries-inhibition Effect and Shear Bond Strength to Enamel

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Abstract

Objectives: To evaluate mineral loss and lesion depth of enamel adjacent to different ion-releasing resin composites in conjunction with artificial caries induction, and to evaluate shear bond strength to enamel.

Methods: Three ion-releasing resin composites (ACTIVA™ BioACTIVE-RESTORATIVE™, BEAUTIFIL Injectable X_{SL} and Cention® N) with or without adhesive system were investigated in comparison with a conventional resin composite (Filtek™ Z350 XT). Effect of Caries Inhibition in Adjacent Enamel – 36 human premolars with cylindrical cavities and filled with restorative materials underwent 14 days of artificial caries induction and were sectioned into two cross-sectional specimens (n=12). Mineral loss and lesion depth were measured at 10, 260, 510, and 760 µm from the tooth-restoration interface and analyzed using repeated measures ANOVA and pairwise comparison for within group comparisons (p<0.05) and One-way ANOVA with Tukey's post hoc test for comparisons among groups (p<0.05). Shear bond strength test – 108 human premolars were embedded in self-curing acrylic resin. A polyethylene tube was placed on each surface and filled with restorative materials. Each group was divided into 2 subgroups (n=9) whether the specimens were thermocycled or not. Shear bond strength was tested with the Instron® 5566 universal testing machine. Failure analysis was conducted using a stereomicroscope. Shear bond strength was analyzed using two-way ANOVA and Tukey's multiple comparison test (p<0.05).

Results: At 14 days post-caries simulation, ACTIVA™ BioACTIVE-RESTORATIVE™ and Cention® N with and without adhesive demonstrated an ability to inhibit caries formation at 10 µm from the restoration-enamel interface. Shear bond strength to enamel of Cention® N with adhesive had the highest values for both non-thermocycling (21.68±1.86 MPa) and thermocycling (21.17±2.4 MPa) condition, being significantly higher than other groups except for the conventional resin composite (20.3±1.85 MPa for non-thermocycling and 19.16±2.29) MPa for thermocycling condition.

Conclusions: The use of Cention® N with adhesive provides the optimal combination of shear bond strength and caries inhibition effect, which is potentially a superior candidate for clear aligner attachments.

Keywords: caries inhibition, clear aligner attachment, ion-releasing resin composite, shear bond strength

Introduction

Orthodontic treatment is a field that combines both physics and biomechanics to correct malocclusions in addressing three main goals: function, occlusal stability, and aesthetics.[1] In recent years, clear aligner treatment has been considered a more comfortable and esthetic alternative to conventional fixed appliance orthodontics, offering certain advantages such as better aesthetics, removability, and smaller dimensions.[2] Attachments are bonded to the tooth surface and work with clear aligners to move teeth in the desired direction.[3]

The selection of attachment materials must consider both physical and mechanical properties. The attachment materials should resist staining and appear similar to that of natural teeth.[4] Mechanically, the material should maintain its shape and integrity throughout the treatment, enduring the forces exerted during eating and the insertion and removal of clear aligners, to effectively facilitate tooth movement throughout the treatment duration.[5,6]

A common issue during treatment with clear removable appliances is the development of initial caries, or white spot lesions around the attachments. This occurs because the appliances or materials attached to the tooth surface make cleaning difficult, leading to the accumulation of plaque and an increase of cariogenic bacteria, which results in demineralization of the enamel.[7]

The choice of restorative materials can affect the mineral shifts (demineralization and remineralization) of tooth structures. Ion-releasing resin composite that can release ions, such as fluoride ions, calcium ions, and phosphate ions, can help reduce mineral loss and promote remineralization of the tooth structure.[8] Additionally, hydroxyl ions help neutralize the acidic environment created by bacteria.[9] These ions play a crucial role in enhancing the tooth structure's resistance to caries.

ACTIVA™ BioACTIVE-RESTORATIVE™ (Activa) is a self-adhesive, bioactive material in a self-mixing syringe that contains high molecular weight polyacrylic acid, similar to that in resin-modified glass ionomers, but without methacrylate polymerizable groups. It includes urethane dimethacrylate monomers and dimethacrylate phosphate, which enhance its mechanical properties and bond strength.[10] It lacks bisphenol A (BPA), bisphenol A-glycidyl methacrylate (bis-GMA), and BPA derivatives, thus avoiding polymerization shrinkage and stress. The fillers used are silanized fluoroaluminosilicate (FAS) and silanized nonreactive fillers, contributing to the material's wear resistance and esthetics.[11] Moreover, when used in conjunction with an adhesive system, Activa has demonstrated comparable bond strengths to nanocomposite.[12] BEAUTIFIL Injectable X_{SL} (X_{SL}), leveraging Giomer technology, is known for its self-leveling properties, which enhance handling and adaptation to cavity walls. The new nano surface pre-reacted glass-ionomer (S-PRG) fillers offer an optimal balance of light transmission and diffusion for a perfect shade match.[13,14]

Cention® N, an alkasite material supplied as a hand-mixed powder and liquid, can be used in bulk, serving as an alternative to amalgam according to the manufacturer. It has reactive silanized fluoro-alumino-silicate glass similar to those used in glass ionomer cement and advertised as highly reactive especially in an acidic environment. It releases fluoride and calcium ions, preventing demineralization and enhancing remineralization of tooth structure,[15] as well as hydroxyl ions, neutralizing acidic conditions.[16] An *in vitro* study reported that Cention® N can form apatite on its surface, thereby remineralizing the underlying dentin.[11] This property classifies Cention® N as a bioactive material, making it a resin composite with proven bioactivity.[17] In terms of bonding properties, Cention® N showed a superior shear bond strength compared to nanohybrid composite and Fuji IX after being exposed to water aging and exhibited lesser marginal leakage.[18]

Previous studies have characterized the fundamental changes that occur in natural white spot lesions (WSLs) from both materials and microstructural perspectives. Huang *et al.,* demonstrated a correlation between elastic modulus and mineral density for the enamel component of WSLs using nanoindentation and computed x-ray microtomography (micro-CT).[19] Micro-CT is a powerful tool to study the demineralization and remineralization of teeth.[20,21] The data on mineral loss and lesion depth in tooth structures obtained from micro-CT indicate the ability of restorative materials to enhance tooth structures resist mineral loss under simulated caries conditions.[22] Additionally, micro-CT provides distinct advantages, such as non-destructive, high-resolution 3D imaging, enabling precise quantification of mineral loss and lesion depth across different depths of enamel and dentin.[23]

Moreover, choosing the most suitable resin composite type to produce durable attachments is consid-

ered challenging. Bonding performance of the attachment material to enamel is important and directly affects the efficiency of tooth movements and treatment outcomes. Research on clear aligner technology is constantly progressing, but studies on the selection of optimal attachment materials to enamel remain relatively limited.[24,25] Two primary types of composite resins are commonly used for fabricating attachments: high-viscosity packable composites and low-viscosity flowable composites. While there is still no consensus on the optimum shear bond strength required for attachments to enamel, previous studies have reported a range of values. High-viscosity composites generally exhibit higher shear bond strength compared to their low-viscosity counterparts.[26] This finding aligns with the study by Chen *et al.* in 2021, which evaluated the shear bond strength of these materials on extracted premolars. The study found that the flowable composite, Filtek™ Z350 XT Flowable, used with two-step total etch adhesive (Adper™ Single Bond 2 Adhesive), demonstrated a lower shear bond strength (15.3±2.33 MPa) compared to the packable composite, Z350 with the two-step total-etch adhesive (20.53±2.59 MPa).[24] Building on this gap, the present investigation aims to analyze three ion-releasing resin composites to compare their effect on caries inhibition in adjacent enamel and shear bond strength to enamel, in order to identify which material is more suitable for attachment reproduction in clear aligner treatment, with and without the use of an adhesive system. The null hypothesis tested was that different restorative materials with or without adhesive would not affect mineral loss and lesion depth on the contiguous enamel or the shear bond strength to enamel.

Materials and Methods

This study was approved by the Human Experimentation Committee, Faculty of Dentistry, Chiang Mai University, Thailand (NO.20/2023).

Materials

Three commercial ion-releasing resin composites: ACTIVA™ BioACTIVE-RESTORATIVE™ (Pulpdent, Massachusetts, USA), BEAUTIFIL Injectable X_{SL} (Shofu, Kyoto, Japan), Cention® N (Ivoclar Vivadent, Schaan, Liechtenstein) and a conventional nanofilled resin composite, Filtek™ Z350 XT Universal Restorative (3M ESPE, Minnesota, USA) were selected. The compositions and product instructions of experimental restorative materials and an adhesive system are shown in Table 1.

Specimen preparation

One hundred and forty-four sound human premolars, extracted for orthodontic and periodontal reasons, were used in this study. All teeth were free of caries, restorations, and dental anomalies. The exclusion criteria were teeth with crown defects, caries, cracks, or restorations. The teeth were immersed in a 0.1% thymol solution at room temperature and used within 3 months of storage.

Effect of caries inhibition in adjacent enamel

The teeth were randomly assigned for two experiments. Thirty-six premolars were sectioned at the cemento-enamel junction using a precision diamond saw (IsoMet™ 1000, Buehler, USA). The buccal sides with enamel surfaces facing up were embedded in self-curing acrylic resin. These surfaces were ground with 600 grit silicon carbide paper to create a flat surface and cleaned with deionized water in an ultrasonic cleaner (BioSonic® UC125: Whaledent Inc., USA) for 10 minutes. Preparations were made at buccal surface with 2 mm wide and 2 mm deep occlusogingivally. The specimens were assigned into six groups based on the restorative materials used: ACTIVA™ BioACTIVE-RESTORATIVE™ (A), BEAUTIFIL Injectable X_{SL} (B), Cention® N (C), and Filtek™ Z350 XT Universal Restorative (F), with Adper™ Single Bond 2 Adhesive (S) as the adhesive system. Activa and Cention® N can be used with or without an adhesive, while X_{SL} and Z350 requires the use of an adhesive. Therefore, the groups were categorized as follows: Group 1: A, Group 2: AS, Group 3: BS, Group 4: C, Group 5: CS, and Group 6: FS. The prepared cavities were filled with the materials according to the manufacturer's recommended directions (Table 1). Filled specimens were stored in deionized water at 37°C for 24 hours. The outer surface of all restored specimens was serially polished with silicon carbine papers of 600, 800, 1000 and 1500 grit to remove the excess and to define the boundary of prepared restoration before being cleaned in ultrasonic cleanser for 10 minutes. Each specimen surface was coated with nail varnish, leaving exposed only half of the restoration and 1 mm of the adjacent enamel beyond the margin on the occlusal side, to allow exposure to the demineralizing and remineralizing solutions. The sound tooth structure on the cervical side, protected by the nail varnish, served as the control within each specimen.

Table 1: The details of the materials and adhesive system.

Materials	Composition	Instructions
ACTIVA™ BioACTIVE-RESTORATIVE™ (Pulpdent, Massachusetts, USA) Lot 210618, shade A2* Lot 230404, shade A3**	Resin matrix: patented ionic resin matrix, shock-absorbing rubberized resin (diurethane and other methacrylates with modified polyacrylic acid 44.6%) Filler: reactive ionomer glass fillers (amorphous silica 6.7%, sodium fluoride 0.75 %, 55.4 wt% of bioactive glass and sodium fluoride)	- Dispense the material into the cavity through a spiral nozzle - Allow the material to self-cure for 20 seconds - Light-cured for 20 seconds
BEAUTIFIL Injectable X_{SL} (Shofu, Kyoto, Japan) Lot 052204, shade B1*,**	Resin matrix: bis-GMA, bis-MPEPP, TEGDMA Filler: F-B-Al-Si-glass (63.4 wt%, 41.7 v%, 0.1-0.8 µm, 0.4 mean) aluminofluoro-borosilicate glass, Al_2O_3, S-PRG filler	- Dispense the material into the cavity - Light-cured for 20 seconds
Cention® N (Ivoclar Vivadent, Schaan, Liechtenstein) Lot Z04YLR, shade A2*,**	Resin matrix: UDMA, DCP, aromatic aliphatic-UDMA, PEG-400 DMA Filler: barium aluminium silicate glass, ytterbium trifluoride, isofiller, calcium barium aluminium fluorosilicate glass, calcium fluorosilicate glass (78.4 wt%, 57.6 v%, 0.1−35 µm) Powder/liquid ratio (g/g) = 4.6/1.0	- Mix the material with a powder-to-liquid ratio of 1:1 (mixing time: 40-60 seconds and setting time: 5 minutes) - Light-cured for 20 seconds
Filtek™ Z350 XT Universal Restorative (3M ESPE, Minnesota, USA) Lot 9712738, shade A1*,**	Resin matrix: bis-GMA, UDMA, TEGDMA, bis-EMA (6) resins Filler: non-agglomerated/non-aggregated 20 nm silica filler, non-agglomerated/non-aggregated 4-11 nm zirconia filler, and aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4-11 nm zirconia particles)	- Place the material into the cavity - Light-cured for 20 seconds
Scotchbond™ Etchant (3M ESPE, Minnesota, USA) Lot 9637865*,**	37% Phosphoric acid	- Apply on enamel for 20 seconds - Rinse thoroughly with water for 10 seconds - Air-dry gently for 2 seconds
Adper™ Single Bond 2 Adhesive (3M ESPE, Minnesota, USA) Lot 9753157*,**	bis-GMA, HEMA, dimethacylates, ethanol, water, photoinitiator, methacrylate functional copolymer of polyacrylic and poly (itaconic) acids, 5 nm spherical silica particles (10 wt%)	- Rub adhesive on enamel for 20 seconds to ensure thorough penetration - Air-dry gently for 5 seconds - Light-cured for 20 seconds

*lot used in the test for effect of caries inhibition in adjacent enamel, **lot used in shear bond strength test

(bis-GMA: bisphenol A-glycidyl methacrylate, DCP: dicalcium phosphate, DMA: dimethacrylate, HEMA: hydroxyethyl methacrylate, PEG: polyethylene glycol, S-PRG: surface pre-reacted glass-ionomer, TEGDMA: triethylene glycol dimethacrylate, UDMA: urethane dimethacrylate)

Artificial caries induction by pH-cycling

All specimens were subjected to 14 days of artificial caries induction or pH-cycling process. Each specimen was submerged in an 8 ml of demineralizing solution (2.2 mM of $CaCl_2$, 2.2 mM of KH_2PO_4 , 0.05 M of acetic acid; pH 4.4) for 6 hours and in an 8 ml of remineralizing solution (1.5 mM $CaCl_2$, 0.9 mM KH_2PO_4, 0.15 M KCl, 20 mM HEPES; pH 7.0) for 18 hours.[27] All specimens were carried out in an incubator at 37°C.

Mineral loss and lesion depth measurement

After 14 days of artificial caries induction, each specimen was perpendicularly sectioned through the buccal enamel. The illustration of the cross-sectional specimen, the area of measurements of mineral loss (ΔZ) and lesion depth (LD) are shown in Figure 1 and Figure 2. Both values were performed by a micro computed tomography (microCT35; SCANCO Medical AG, Switzerland) under standardized conditions of 70 kV voltage, 114 µA current,

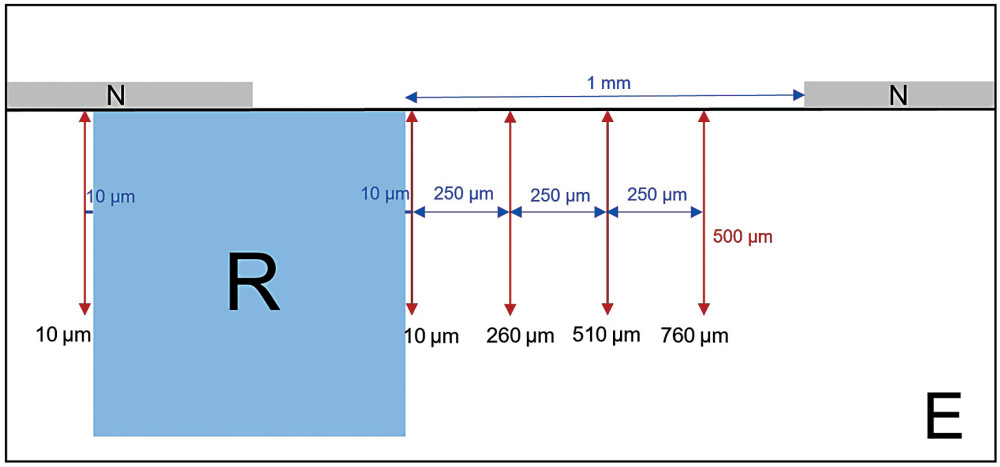

Figure 1: The cross-sectional specimen, along with the locations for mineral loss and lesion depth measurements. E: Enamel, N: Nail varnish, R: Restoration. (Modified from Kuphasuk *et al.,* 2022)

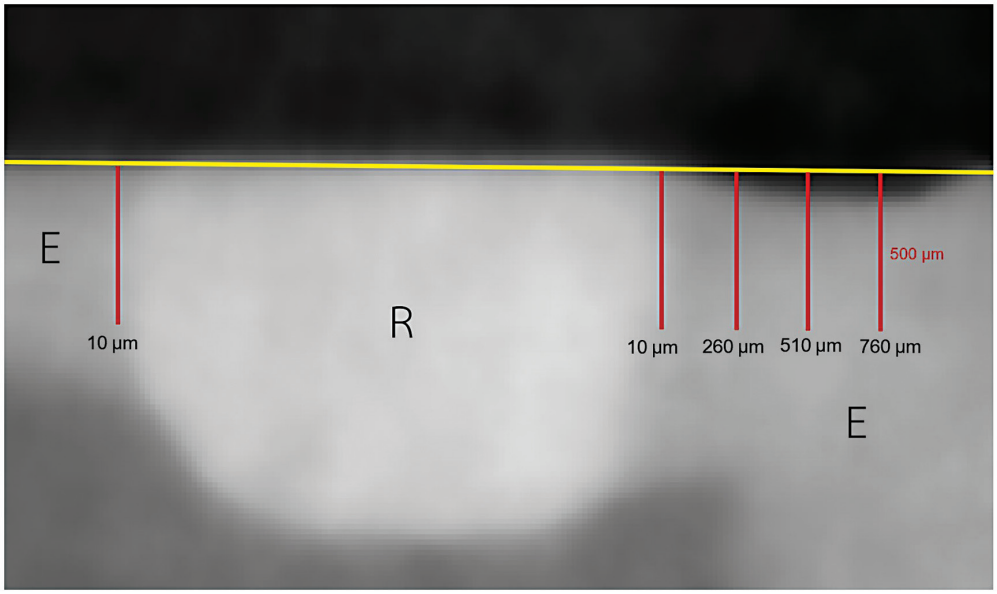

Figure 2: Cross-sectional specimen obtained from micro-CT imaging, along with the locations for mineral loss and lesion depth measurements. E: Enamel, N: Nail varnish, R: Restoration.

and 5 µm voxel dimensions. The radiolucency and radiopacity of the micro-CT images were calibrated against a phantom with known mineral density standards to obtain quantitative mineral profiles for each specimen. Mineral loss was calculated as the integrated difference in mineral volume between the demineralized region and sound enamel using an image processing program (Rasband, W.S., ImageJ, U.S. National Institutes of Health, USA). Lesion depth was determined as the distance where the mineral content dropped below 95% of the mineral density of sound enamel, indicating significant demineralization.[28] Both parameters were evaluated at four predefined distances from the restoration-enamel interface: 10 µm, 260 µm, 510 µm, and 760 µm, measured across a depth of 500 µm from the tooth surface.[29] The evaluation procedure, including the preparation of specimens and the pH cycling model, is summarized and illustrated in Figure 3.

Shear bond strength test

One hundred and eight premolars were sectioned at the cemento-enamel junction using a precision diamond saw. The buccal sides with the enamel surface facing up were embedded in self-curing acrylic resin (18 mm diameter, 10 mm height). The enamel surfaces were

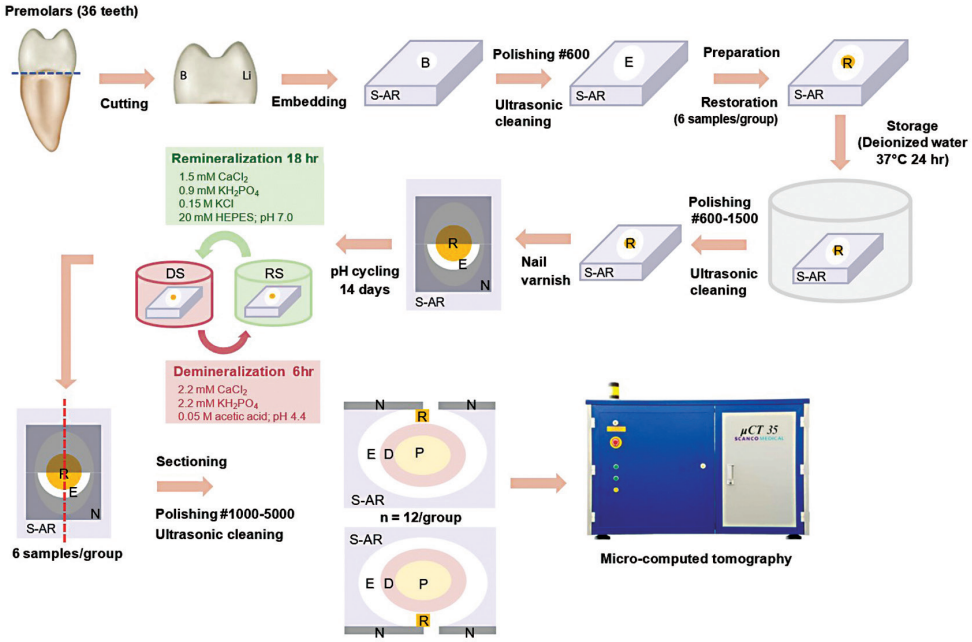

Figure 3: The procedures for specimen preparation to evaluate the effect of ion releasing resin composite material on caries-inhibition potential in conjunction with pH cycling. B: buccal, D: dentin, DS: demineralizing solution, E: enamel, Li: lingual, N: nail varnish, P: pulp, RS: remineralizing solution, S-AR: self-curing acrylic resin.

ground flat with 600-grit silicon carbide paper and cleaned in an ultrasonic cleanser for 10 minutes. A polyethylene tube (1.8 mm internal diameter, 2 mm height) was placed on each surface and filled with different restorative materials per group. All specimens were stored in deionized water at 37°C for 24 hours and inspected for defects under the stereomicroscope. Each group was divided into two subgroups (n=9): one subgroup underwent 10,000 thermocycling cycles, and the other was assigned as non-thermocycling. Shear bond strength was tested with the Instron® 5566 universal testing machine using a knife edge chisel at a cross-head speed of 1 mm/min. Failure mode analysis was performed with a stereomicroscope and digital camera, categorizing failure modes into four types:[30]

• Type 1: Adhesive failure (over 80% at the restoration-enamel interface)

• Type 2: Mixed failure (combination of adhesive failure at the interface and cohesive failure in restoration and/or enamel)

• Type 3: Cohesive failure in enamel (over 80% in the underlying enamel)

• Type 4: Cohesive failure in restoration (over 80% in the adhesive resin and/or restoration)

The procedures for preparing specimens to evaluate the shear bond strength of ion-releasing resin composite to enamel, are summarized and illustrated in Figure 4.

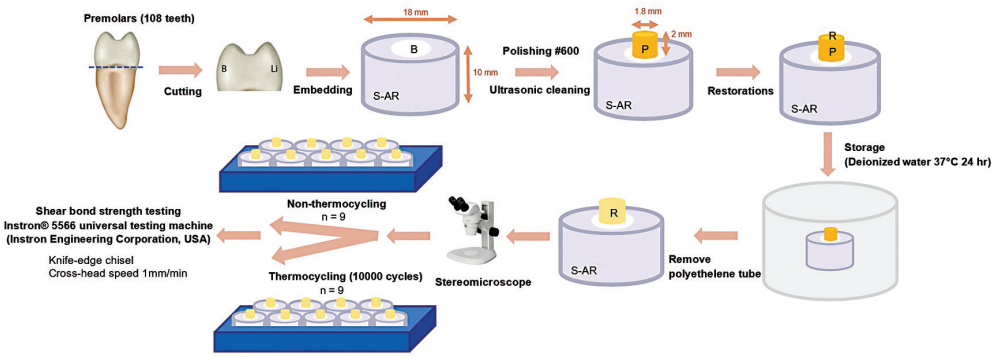

Figure 4: The procedures of specimen preparation to evaluate the effect of ion-releasing resin composite material on shear bond strength to enamel. B: buccal, Li: lingual, P: polyethylene tube, R: restoration, S-AR: self-curing acrylic resin.

Table 2: Means and standard deviations of mineral loss (mgHAP/m^2) at different distances for each group after 14 days of artificial caries induction. Different superscript lowercase letters indicate significant differences within the same row (p<0.05). Different superscript uppercase letters indicate significant differences within the same column (p<0.05).

Groups			Column			
Materials		code	1 (10 µm) (gHAP/m^2)	2 (260 µm) (gHAP/m^2)	3 (510 µm) (gHAP/m^2)	4 (760 µm) (gHAP/m^2)
ACTIVA™ BioACTIVE-RESTORATIVE™	no bonding	A	19.37±2.66^{aA}	104.69±17.25^{bA}	130.13±18.72^{cA}	162.91±18.98^{dA}
	with two-step total etch	AS	48.59±3.22^{aBC}	143.50±13.25^{bBC}	189.10±19.38^{cBC}	221.39±16.73^{dB}
BEAUTIFIL Injectable X_{SL}	with two-step total etch	BS	73.09±5.51^{aD}	125.83±14.12^{bB}	172.44±9.63^{cB}	207.96±11.71^{dB}
Cention® N	no bonding	C	23.21±4.51^{aA}	150.45±15.31^{bCD}	195.33±18.30^{cCD}	249.23±11.79^{dC}
	with two-step total etch	CS	38.16±2.90^{aB}	172.39±18.04^{bDE}	216.19±14.63^{cDE}	255.05±10.74^{dC}
Filtek™ Z350 XT Universal Restorative	with two-step total etch	FS	113.79±19.73^{aE}	223.74±7.22^{bF}	250.21±10.29^{cF}	301.34±15.08^{dD}

Table 3: Means and standard deviations of lesion depth (µm) at different distances for each group after 14 days of artificial caries induction. Different superscript lowercase letters indicate significant differences within the same row (p<0.05). Different superscript uppercase letters indicate significant differences within the same column (p<0.05).

Groups			Column			
Materials		code	1 (10 µm) (µm)	2 (260 µm) (µm)	3 (510 µm) (µm)	4 (760 µm) (µm)
ACTIVA™ BioACTIVE-RESTORATIVE™	no bonding	A	39.39±6.02^{aAB}	162.75±27.06^{bA}	215.29±30.31^{cA}	261.5±30.25^{dA}
	with two-step total etch	AS	63.73±7.76^{aC}	222.42±26.85^{bB}	291.73±21.07^{cBC}	321.62±27.42^{dB}
BEAUTIFIL Injectable X_{SL}	with two-step total etch	BS	120.72±21.69aDE	226.59±28.35^{bB}	278.52±30.58^{cB}	307.53±20.98^{dB}
Cention® N	no bonding	C	37.01±8.74^{aA}	222.7±18.07^{bB}	304.14±11.96^{cBCD}	375.26±41.51^{dC}
	with two-step total etch	CS	60.89±0.25^{aBC}	251.87±34.33^{bBC}	321.03±21.08^{cCD}	370.63±28.06^{dC}
Filtek™ Z350 XT Universal Restorative	with two-step total etch	FS	168.54±26.87^{aF}	324.73±20.23^{bD}	366.35±23.9^{cE}	423.61±22.1^{dD}

Statistical analysis

Statistical analysis was conducted using IBM SPSS Statistics Version 25 (IBM Corporation, Armonk, NY, USA) at a 95% confidence level. Normality and homogeneity tests were performed to confirm normal distribution and homogeneity of variances. Repeated measures ANOVA and pairwise comparison were used to compare mineral loss and lesion depth within group, while One-way ANOVA with Tukey's post hoc test for comparisons among groups (p<0.05). Shear bond strength was analyzed using two-way ANOVA and Tukey's multiple comparison test (p<0.05).

Result

Effect of caries inhibition in adjacent enamel

Mineral loss and lesion depth values of the adjacent enamel at various distances for each group are detailed in Table 2 and Table 3. X-ray images obtained from the micro-CT machine showing the enamel adjacent to each restoration group are presented in Figure 5. Within the same sample, every group exhibited significant differences in mineral loss and lesion depth values at different distances from the restoration-enamel interface (p<0.05). When comparing mineral loss and lesion depth values among groups at a distance of 10 µm, group A showed the

Table 4: Means and standard deviations of shear bond strength (MPa) to enamel before and after thermocycling 10000 cycles and percentage of each mode of failure. Superscript uppercase letters indicate significant differences between different storage conditions within each material tested. Asterisk (*) indicates significant differences between groups within the same material ($p<0.05$).

Materials		Thermocycling	code	SBS (MPa)
ACTIVA™ BioACTIVE-RESTORATIVE™	no bonding	24 hours	A-t_0	14.10 ± 2.03^{D}
		10,000 thermocycles	A-t_1	$7.10 \pm 0.80^{E*}$
	with two-step total etch	24 hours	AS-t_0	15.13 ± 1.76^{D}
		10,000 thermocycles	AS-t_1	13.99 ± 1.74^{D}
BEAUTIFIL Injectable X_{SL}	with two-step total etch	24 hours	BS-t_0	17.90 ± 1.45^{BC}
		10,000 thermocycles	BS-t_1	16.38 ± 1.54^{CD}
Cention® N	no bonding	24 hours	C-t_0	7.52 ± 1.19^{E}
		10,000 thermocycles	C-t_1	$4.08 \pm 0.51^{F*}$
	with two-step total etch	24 hours	CS-t_0	21.68 ± 1.86^{A}
		10,000 thermocycles	CS-t_1	21.17 ± 2.40^{A}
Filtek™ Z350 XT Universal Restorative	with two-step total etch	24 hours	FS-t_0	20.30 ± 1.85^{AB}
		10,000 thermocycles	FS-t_1	19.16 ± 2.29^{AB}

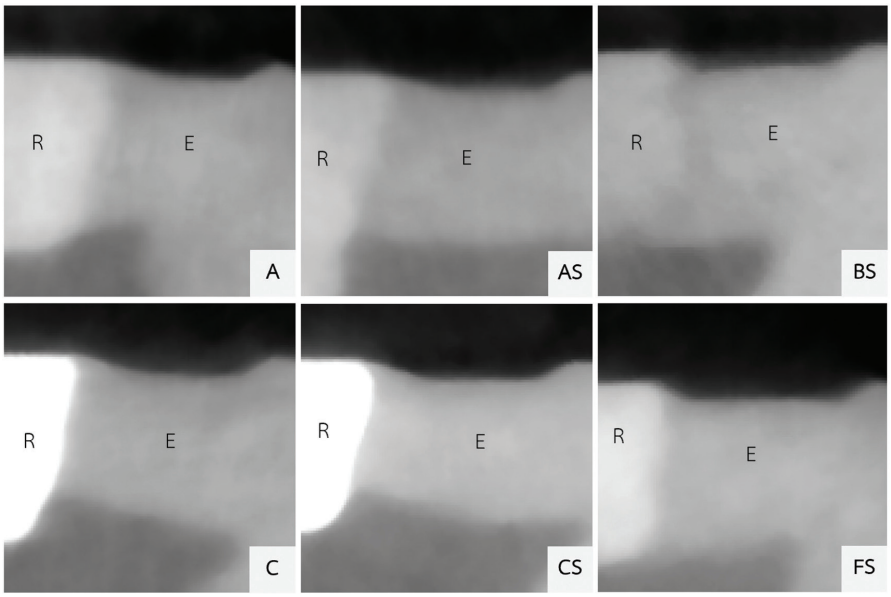

Figure 5: X-ray images obtained from the micro-CT machine show the enamel adjacent to each restoration group after 14 days of pH cycling. A: ACTIVA™ BioACTIVE-RESTORATIVE™, AS: ACTIVA™ BioACTIVE-RESTORATIVE™ with two-step total etch, BS: BEAUTIFIL Injectable XSL with two-step total etch, C: Cention® N, CS: Cention® N with two-step total etch, E: enamel, FS: Filtek™ Z350 XT with two-step total etch, R: restoration.

lowest value and significant differences compared to the other groups, except for the group C. Group FS exhibited the highest, showing significant differences compared to the other groups ($p<0.05$). At distances of 260, 510 and 760 µm, group A remained the lowest and Group FS remained the highest in mineral loss and lesion depth value and showed significant differences compared to the other groups.

Shear bond strength test

The comparison of shear bond strength values between groups as shown in Table 4 revealed that Cention® N with an adhesive system had the highest values for both thermocycling and non-thermocycling conditions, which was significantly higher than other groups except that of

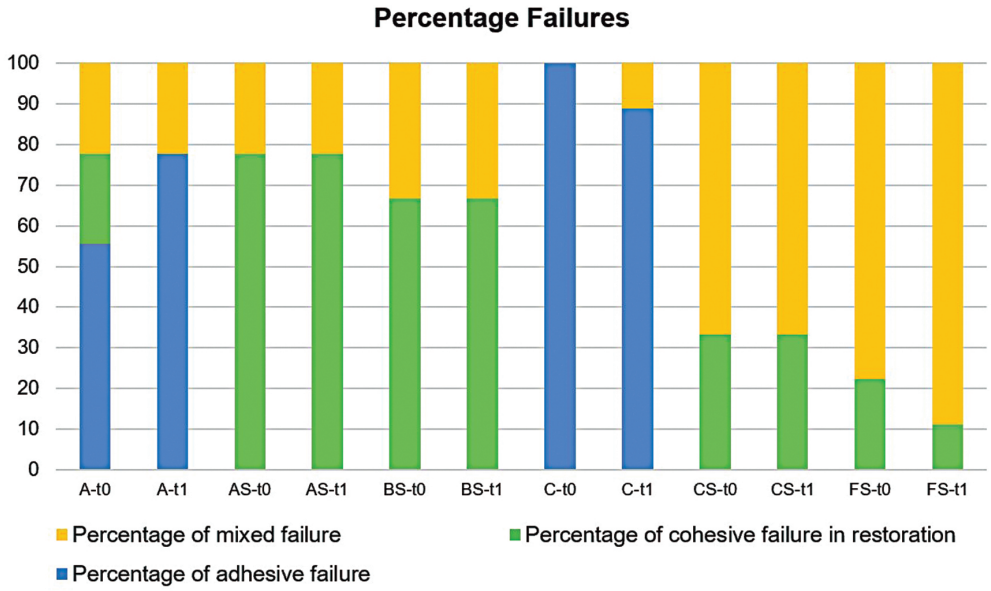

Figure 6: Percentage of failure mode.

the conventional resin composite with an adhesive system. Conversely, Cention® N without an adhesive system had the lowest values, significantly different from all other groups ($p<0.05$).

When considering the shear bond strength within the group, by comparing conditions with and without thermocycling, it was found that the group subjected to 10,000 cycles of thermocycling exhibited lower shear bond strength than the group that did not undergo thermocycling. The lower value was statistically significant in the group without an adhesive system ($p<0.05$). Whereas in the group with adhesive system, although a lower value of shear bond strength was observed, the difference was not statistically significant ($p>0.05$).

Failure mode analysis (Figure 6) showed that adhesive failure was predominant in the groups without an adhesive system. Cohesive failure within the restoration was predominantly observed in group AS and BS, whereas mixed failure was primarily noted in group CS and FS.

Discussion

Composite attachments serve as a component that bonds to the tooth surface, working in conjunction with clear aligners; it increases the surface area in contact with the aligners, allowing for better control of tooth movement in the desired direction.[3] Therefore, selection of composite attachment plays a crucial role for the long-term stability of the attachments' shape and for their structural integrity.

Ion-releasing resin composites signify a notable advancement in dental restorative materials. These innovative composites are designed to restore the structural integrity of teeth while actively preventing secondary caries through the release of therapeutic ions.[31]

The caries inhibition effects of restorative materials manifest in two distinct forms based on the alterations in tooth structure. The first form is the caries inhibition zone, which develops adjacent to fluoride-releasing materials due to ion infiltration and fluoride accumulation, enhancing the acid resistance in that area.[32,33] The second form is the acid-base resistant zone beneath the hybrid layer, which shows greater resistance to environmental acids and bases than normal tooth structure.[34,35] Previous studies have demonstrated that 10-MDP in primers or bonding agents forms stable, low-solubility salts with calcium in hydroxyapatite, which are crucial for creating an acid-base resistant zone in the enamel.[36,37]

When considering the lesion depth of enamel columns at a distance of 10 µm from the restoration-enamel interface, it was found that groups A, AS, C, and CS exhibited lesion depths of less than 100 µm (Table 3). In contrast, groups BS and FS exhibited lesion depths of more than 100 µm at all distances. Studies have shown that the lesion depth of initial caries ranges from 100 to 500 µm.[19,38] This indicates that at 14 days post-caries simulation, the use of Activa and Cention® N with and

without adhesive demonstrated the ability to inhibit caries formation in columns 10 μm from the restoration-enamel interface. According to the study by Ruengrungsom *et al.,* Cention® N exhibited a higher and more substantial fluoride ion release compared to Activa.[8] The results align with the trend observed in recent studies.[11] This is due to the fluoride-containing fillers in Cention® N, which release fluoride ions in deionized water, whereas bioactive glass typically releases fluoride ions under acidic conditions.[8,11] Additionally, Cention® N was found to release a higher amount of calcium ions than Activa, attributable to its composition of calcium fluorosilicate glass or bioactive glass-like phase, and calcium barium aluminum fluorosilicate glass or ionomer glass-like phase, similar to those in glass ionomer cements. Activa, on the other hand, contains only the ionomer phase. However, Activa was found to release a high amount of phosphate ions, due to its phosphate-containing fillers.[8]

The caries-inhibitory potential of ion-releasing restorative materials is primarily linked to their ability to release beneficial ions, with fluoride playing a crucial role in this process.[39,40] Studies indicate that Cention® N releases significantly greater quantities of fluoride and calcium ions compared to conventional resin composites, with concentrations approximately 300-400 times higher.[8,11,41] This enhanced ion release is associated with a notable reduction in Streptococcus mutans colonization, a key contributor to biofilm formation and the progression of carious lesions.[42] This substantial ion release may account for the reduced lesion depth and lesser demineralization at all depths, compared to the control resin composite.[43] Conversely, Activa has been shown to release minimal amounts of calcium and relatively low concentrations of fluoride, which are unlikely to significantly reduce biofilm formation.[8,11,42]

Giomer incorporates pre-reacted glass (PRG) filler technology, utilizing ionomer-like fluorosilicate glasses that pre-reacted with polyacrylic acid and are dispersed in the resin matrix.[44] Fluoride release in giomers occurs through water diffusion. When bioactive glass containing fluoride is included ion-releasing resin composite, the bioactive glass functions as an ion source, releasing ions such as Ca, P, and F. This process is initiated upon contact with fluid, even under neutral pH conditions, enabling controlled fluoride release.[11] The level of fluoride release from ion-releasing resin composite is affected by the hydrophilic and acidic properties of their resin matrices.[45] However, PRG fillers combined with bis-GMA/TEGDMA resin have shown a lower capacity to facilitate fluoride diffusion in deionized water compared to other materials.[8]

When comparing the use of an adhesive system with the same restorative material, the micro-CT evaluation revealed that at a distance of 10 μm from the restoration-enamel interface, group A exhibited significantly less mineral loss than group AS. Similarly, group C showed significantly less mineral loss than group CS (Table 2). These findings align with several studies that have reported that the presence of an adhesive layer can interfere the release of fluoride ions from fluoride-releasing resin composites.[46,47] This interference occurs because fluoride release is facilitated by the infiltration and diffusion of water into the material. Therefore, when an adhesive is used, water must first penetrate the adhesive layer. A study by Burrow *et al.,* found that physical properties such as water sorption and desorption of the adhesive are crucial factors in controlling fluoride release.[48]

Analysis of mineral loss and lesion depth in enamel for the same restorative material group, at varying distances from the restoration-enamel interface, revealed that all groups exhibited a gradient of increasing mineral loss and lesion depth from column 1 to column 4 (Table 2 and Table 3). Each column showed statistically significant differences, indicating that enamel closer to the restoration-enamel interface had less mineral loss and shallower lesion depths than enamel further away from the interface. This effect is attributed to higher fluoride exposure near the restorative material, consistent with multiple studies reporting that the tooth structure near fluoride-releasing restorative materials had mineral density and surface hardness similar to normal tooth structure, and higher than tooth structure further from the restoration-enamel interface.[29,49] The ion-releasing mechanisms of the experimental restorative materials vary significantly. Activa releases fluoride, calcium, and phosphate ions through an acid-base reaction, similar to glass ionomers, and promotes remineralization via its polyacrylic acid component.[8] Cention® N releases fluoride, calcium, and hydroxyl ions primarily under acidic conditions, aiding in remineralization and neutralizing oral acids. It achieves this through its unique alkaline fillers.[8,15,16] X_{SL} features S-PRG fillers that release fluoride and other ions. These differences in

ion releasing behavior directly influence the gradient of mineral loss observed in the enamel with materials that have more active and targeted ion release, such as Activa and Cention® N, showing localized effects near the restoration-enamel interface and leading to reduced lesion depth and mineral loss in adjacent enamel.

Selecting an attachment material with optimal bonding properties to the enamel surface is crucial for the success of clear aligner orthodontic treatment. The effectiveness of clear aligners in moving teeth to the desired positions depends on the stability of the attachment bond.(50) If the attachment bond is insufficient, the attachments may detach, resulting in poor control of tooth movement and prolonged treatment duration.(51)

The analysis of shear bond strength values to enamel indicated that ion-releasing resin composites exhibited significantly lower shear bond strength compared to conventional resin composites. However, Cention® N, when used with an adhesive system, demonstrated no significant difference in shear bond strength compared to the conventional resin composite group in both thermocycling and non-thermocycling conditions (Table 4). One key factor contributing to the differences in shear bond strength among various materials is the amount of inorganic filler. Higher inorganic filler content results in lower polymerization shrinkage, thereby enhancing bond strength.(52) Specifically, the inorganic filler content is 78.5% by weight for Z350, 78.4% for Cention® N, 63.4% for X_{SL}, and 55.4% for Activa. The higher filler content in Z350 and Cention® N contributes to their improved bond strength due to reduced polymerization shrinkage, compared to X_{SL} and Activa.

Activa exhibits bend before failure due to its low flexural modulus.(53) A low flexural modulus leads to high distortion, an undesirable property in materials.(54) This can affect material strength and cause uneven stress distribution from chewing forces.(53,54) This study found that using Activa with an adhesive resulted in cohesive failure within the composite resin layer during shear bond strength tests. In contrast, groups using Cention® N and Z350 exhibited mixed failure modes. This difference is likely due to the higher mechanical strength and shear bond strength of Cention® N and the conventional resin, resulting in a combination of cohesive failure within the composite resin layer and adhesive failure at the bonding interface. Across all experimental groups, the observed failure modes included adhesive failure, mixed failure, and cohesive failure within the composite resin layer. Notably, no cohesive failures were observed within the enamel layer, indicating that the enamel remained intact. This finding highlights the safety and clinical suitability of the adhesives and restorative materials evaluated in this study for use in attachment bonding in clear aligner therapy.

Factors such as depth of cure (DoC) and Knoop microhardness also impact the bond strength to tooth structure. A study by Daabash *et al.,* found that Cention® N has a greater DoC than Activa and Z350.(54) Cention® N initiates polymerization with both chemical and light activation, aided by Ivocerin™ and acyl phosphine oxide, which absorb visible light between 370 and 460 nm, and its high translucency enhances light transmission. In contrast, despite manufacturer claims, Activa, with a stated DoC of 4 mm and a combination of acid-base and photopolymerization reactions, showed no DoC enhancement after 24 hours, indicating a less effective chemical cure compared to Cention® N.(54) This aligns with a study by Hughes *et al.,* which reported Activa's limited self-curing ability despite being marketed as a dual-cure material.(55)

Selecting restorative materials for orthodontic attachments requires balancing adequate bond strength and the added benefit of caries inhibition. The study results indicate that Cention® N, with its high filler content and fluoride release, excels in both bond strength and caries inhibition, although its hand-mixing requirement can be a downside. Z350 also demonstrates superior mechanical properties, making it a reliable choice for durable attachments. X_{SL} exhibited a lower shear bond strength than Cention® N, comparable to Z350, and higher than Activa, but lacks caries inhibition effects, similar to Z350. Activa, while beneficial for its caries inhibition effect, shows limitations in mechanical strength and shear bond strength. Notably, all materials showed significantly lower shear bond strength without an adhesive system, which is insufficient to withstand the insertion and removal of clear aligner trays. These insights guide the selection of materials to improve the efficacy and safety of clear aligner treatments.

In vitro pH cycling models remain widely used as they simulate daily pH changes in the oral cavity and mimic the dynamic processes of mineral changes asso-

ciated with caries formation.[27] The duration of the demineralization phase was regulated to replicate both high- and low-cariogenic pH cycling scenarios, as demonstrated in Wierich's study.[56] Longer demineralization process are more representative of individuals at high caries risk, where the oral environment remains predominantly in a state of demineralization.[56,57] A six-hour demineralization period is commonly employed in in vitro studies to replicate the acidic exposure that occurs during and after meals, particularly in high-cariogenic environments.[29,58,59] This duration reflects typical acid challenge scenarios within the oral cavity and provides a controlled framework for evaluating the material's response under conditions that mimic real-life clinical situations.[57] Moreover, after 14 days of pH-cycling, the formation of demineralized lesions was the result of a continuous process involving both demineralization and remineralization. The ion-releasing resin composite demonstrated reduced lesion depth and mineral loss compared to the conventional resin composite.

The limitations of this *in vitro* study include its inability to fully replicate the complexity of *in vivo* conditions, such as the ionic composition of dietary foods and drinks, intraoral pH fluctuations, and the presence of salivary enzymes.[60,61] While this study used a controlled environment to isolate and assess specific factors, future investigations should incorporate biological elements such as salivary proteins and enzymes, which play significant roles in remineralization.[62] While the ion-releasing effects of the materials tested are likely influenced by interactions with both tooth structure and the surrounding media, the controlled environment employed in this study provides a close approximation of the material's behavior in clinical scenarios. Future studies should develop experimental models that better simulate the oral environment.

Conclusions

The null hypothesis of this study was rejected. The results of this *in vitro* study indicated that Cention® N, when used with an adhesive system, provides the optimal combination of shear bond strength and caries inhibition effect for the clear aligner attachments.

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Conflicts of Interest

The authors declare no conflict of interest.

References

1. Jamilian A, Kiaee B, Sanayei S, Khosravi S, Perillo L. Orthodontic treatment of malocclusion and its impact on oral health-related quality of life. Open Dent J. 2016;10:236-41.
2. Morton J, Derakhshan M, Kaza S, Li C, Chen V. Design of the invisalign system performance. Semin Orthod. 2016;23(1):3-11.
3. Jedliński M, Mazur M, Greco M, Belfus J, Grocholewicz K, Janiszewska-Olszowska J. Attachments for the orthodontic aligner treatment-atate of the art-a comprehensive systematic review. Int J Environ Res Public Health. 2023;20(5):4481.
4. Feinberg KB, Souccar NM, Kau CH, Oster RA, Lawson NC. Translucency, stain resistance, and hardness of composites used for invisalign attachments. J Clin Orthod. 2016;50(3):170-6.
5. Barreda GJ, Dzierewianko EA, Muñoz KA, Piccoli GI. Surface wear of resin composites used for Invisalign® attachments. Acta Odontol Latinoam. 2017;30(2):90-5.
6. Kravitz ND, Kusnoto B, Agran B, Viana G. Influence of attachments and interproximal reduction on the accuracy of canine rotation with invisalign. a prospective clinical study. Angle Orthod. 2008;78(4):682-7.
7. Julien KC, Buschang PH, Campbell PM. Prevalence of white spot lesion formation during orthodontic treatment. Angle Orthod. 2013;83(4):641-7.
8. Ruengrungsom C, Burrow MF, Parashos P, Palamara JEA. Evaluation of F, Ca, and P release and microhardness of eleven ion-leaching restorative materials and the recharge efficacy using a new Ca/P containing fluoride varnish. J Dent. 2020;102:103474. doi: 10.1016/j.jdent.2020.103474.
9. Persson A, Lingstrom P, van Dijken JW. Effect of a hydroxyl ion-releasing composite resin on plaque acidogenicity. Caries Res. 2005;39(3):201-6.
10. Porenczuk A, Jankiewicz B, Naurecka M, Bartosewicz B, Sierakowski B, Gozdowski D, *et al*. A comparison of the remineralizing potential of dental restorative materials by analyzing their fluoride release profiles. Adv Clin Exp Med. 2019;28(6):815-23.
11. Tiskaya M, Al-Eesa NA, Wong FSL, Hill RG. Characterization of the bioactivity of two commercial composites. Dent Mater. 2019;35(12):1757-68.
12. Rifai H, Qasim S, Mahdi S, Lambert MJ, Zarazir R, Amenta F, *et al*. *In vitro* evaluation of the shear bond strength and fluoride release of a new bioactive dental composite material. J Clin Exp Dent. 2022;14(1):e55-e63.
13. Ltd. SDA-PP. BEAUTIFIL Injectable X : The one true bioactive injectable restorative [Internet]. 2021 [Available from:

https://www.shofu.com.sg/wp-content/uploads/2021/06/BInjectableX-ref-1.pdf.
14. Bai X, Chen Y, Zhou T, Pow EHN, Tsoi JKH. The chemical and optical stability evaluation of injectable restorative materials under wet challenge. J Dent. 2024;146:105031.
15. Ilie N. Comparative effect of self- or dual-curing on polymerization kinetics and mechanical properties in a novel, dental-resin-based composite with alkaline filler. running title: resin-composites with alkaline fillers. Materials (Basel). 2018;11(1):108.
16. Gupta N, Jaiswal S, Nikhil V, Gupta S, Jha P, Bansal P. Comparison of fluoride ion release and alkalizing potential of a new bulk-fill alkasite. J Conserv Dent. 2019;22(3):296-9.
17. Francois P, Fouquet V, Attal JP, Dursun E. Commercially available fluoride-releasing restorative materials: a review and a proposal for classification. Materials (Basel). 2020;13(10):2313.
18. Witty D, Kumaran P, Varma B, J SK, Xavier AM, Venugopal M, *et al*. Effect of prolonged water aging on the bond strength and marginal seal of three novel restorative materials. J Contemp Dent Pract. 2023;24(9):632-7.
19. Huang TT, He LH, Darendeliler MA, Swain MV. Correlation of mineral density and elastic modulus of natural enamel white spot lesions using x-ray microtomography and nanoindentation. Acta Biomater. 2010;6(12):4553-9.
20. Cochrane NJ, Cai F, Huq NL, Burrow MF, Reynolds EC. New approaches to enhanced remineralization of tooth enamel. J Dent Res. 2010;89(11):1187-97.
21. Pires PM, Santos TPD, Fonseca-Gonçalves A, Pithon MM, Lopes RT, Neves AA. A dual energy micro-CT methodology for visualization and quantification of biofilm formation and dentin demineralization. Arch Oral Biol. 2018;85:10-5. doi: 10.1016/j.archoralbio.2017.09.034.
22. Mahoney E, Ismail FS, Kilpatrick N, Swain M. Mechanical properties across hypomineralized/hypoplastic enamel of first permanent molar teeth. Eur J Oral Sci. 2004;112(6): 497-502.
23. Swain MV, Xue J. State of the art of micro-CT applications in dental research. Int J Oral Sci. 2009;1(4):177-88.
24. Chen W, Qian L, Qian Y, Zhang Z, Wen X. Comparative study of three composite materials in bonding attachments for clear aligners. Orthod Craniofac Res. 2021;24(4):520-7.
25. Kircelli BH, Kilinc DD, Karaman A, Sadry S, Gonul EY, Gögen H. Comparison of the bond strength of five different composites used in the production of clear aligner attachments. J Stomatol Oral Maxillofac Surg. 2023;124(6):101481.
26. Alsaud BA, Hajjaj MS, Masoud AI, Abou Neel EA, Abuelenain DA, Linjawi AI. Bonding of clear aligner composite attachments to ceramic materials: an *in vitro* study. Materials (Basel). 2022;15(12):4145.
27. ten Cate JM, Duijsters PP. Alternating demineralization and remineralization of artificial enamel lesions. Caries Res. 1982;16(3):201-10.
28. Arends J, ten Bosch JJ. Demineralization and remineralization evaluation techniques. J Dent Res. 1992;71 Spec No: 924-8.
29. Kuphasuk S, Kunawarote S. *In vitro* caries inhibition in enamel adjacent to ion-releasing resin composite. CM Dent J. 2022;43(2):50-61.
30. Thitthaweerat S, Klinklao K, Senawongse P. Effect of modified smear layer on the bond strength of all-in-one adhesives to dentin. M Dent J. 2018;38(1):11-21.
31. Dionysopoulos D, Koliniotou-Koumpia E, Helvatzoglou-Antoniades M, Kotsanos N. *In vitro* inhibition of enamel demineralisation by fluoride-releasing restorative materials and dental adhesives. Oral Health Prev Dent. 2016;14(4):371-80.
32. Nagamine M, Itota T, Torii Y, Irie M, Staninec M, Inoue K. Effect of resin-modified glass ionomer cements on secondary caries. Am J Dent. 1997;10(4):173-8.
33. Itota T, Nakabo S, Iwai Y, Konishi N, Nagamine M, Torii Y, *et al*. Effect of adhesives on the inhibition of secondary caries around compomer restorations. Oper Dent. 2001;26(5):445-50.
34. Nikaido T, Takahashi R, Ariyoshi M, Sadr A, Tagami J. Protection and reinforcement of tooth structures by dental coating materials. Coatings. 2012;2(4):210-20.
35. Nikaido T, Weerasinghe DD, Waidyasekera K, Inoue G, Foxton RM, Tagami J. Assessment of the nanostructure of acid-base resistant zone by the application of all-in-one adhesive systems: super dentin formation. Biomed Mater Eng. 2009;19(2-3):163-71.
36. Li N, Nikaido T, Takagaki T, Sadr A, Makishi P, Chen J, *et al*. The role of functional monomers in bonding to enamel: acid-base resistant zone and bonding performance. J Dent. 2010;38(9):722-30.
37. Nikaido T, Ichikawa C, Li N, Takagaki T, Sadr A, Yoshida Y, *et al*. Effect of functional monomers in all-in-one adhesive aystems on formation of enamel/dentin acid-base resistant zone. Dent Mater J. 2011;30(5):576-82.
38. Cochrane NJ, Anderson P, Davis GR, Adams GG, Stacey MA, Reynolds EC. An x-ray microtomographic study of natural white-spot enamel lesions. J Dent Res. 2012;91(2): 185-91.
39. Donly KJ, Segura A. Fluoride release and caries inhibition associated with a resin-modified glass-ionomer cement at varying fluoride loading doses. Am J Dent. 2002;15(1):8-10.
40. Kozai K, Suzuki J, Okada M, Nagasaka N. *In vitro* study of antibacterial and antiadhesive activities of fluoride-containing light-cured fissure sealants and a glass ionomer liner/base against oral bacteria. ASDC J Dent Child. 2000;67(2):117-22, 82-3.
41. Di Lauro A, Di Duca F, Montuori P, Dal Piva AMO, Tribst JPM, Borges ALS, *et al*. Fluoride and calcium release from alkasite and glass ionomer restorative dental materials: *in*

vitro study. J Funct Biomater. 2023;14(2):109.
42. Daabash R, Alqahtani MQ, Price RB, Alshabib A, Niazy A, Alshaafi MM. Surface properties and *Streptococcus mutans* biofilm adhesion of ion-releasing resin-based composite materials. J Dent. 2023;134:104549.
43. Albelasy EH, Chen R, Fok A, Montasser M, Hamama HH, Mahmoud SH, *et al*. Inhibition of caries around restoration by ion-releasing restorative materials: an *in vitro* optical coherence tomography and micro-computed tomography evaluation. Materials (Basel). 2023;16(16):5558.
44. Colceriu Burtea L, Prejmerean C, Prodan D, Baldea I, Vlassa M, Filip M, *et al*. New pre-reacted glass containing dental composites (giomers) with improved fluoride release and biocompatibility. Materials (Basel). 2019;12(23):4021.
45. Asmussen E, Peutzfeldt A. Long-term fluoride release from a glass ionomer cement, a compomer, and from experimental resin composites. Acta Odontol Scand. 2002;60(2):93-7.
46. Itota T, Nakabo S, Narukami T, Tashiro Y, Torii Y, McCabe JF, *et al*. Effect of two-step adhesive systems on inhibition of secondary caries around fluoride-releasing resin composite restorations in root dentine. J Dent. 2005;33(2):147-54.
47. Vercruysse CW, De Maeyer EA, Verbeeck RM. Fluoride release of polyacid-modified composite resins with and without bonding agents. Dent Mater. 2001;17(4):354-8.
48. Burrow MF, Inokoshi S, Tagami J. Water sorption of several bonding resins. Am J Dent. 1999;12(6):295-8.
49. Serra MC, Cury JA. The *in vitro* effect of glass-ionomer cement restoration on enamel subjected to a demineralization and remineralization model. Quintessence Int. 1992;23(2):143-7.
50. Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL. Efficacy of clear aligners in controlling orthodontic tooth movement: a systematic review. Angle Orthod. 2015;85(5):881-9.
51. Kravitz ND, Kusnoto B, BeGole E, Obrez A, Agran B. How well does invisalign work? a prospective clinical study evaluating the efficacy of tooth movement with invisalign. Am J Orthod Dentofacial Orthop. 2009;135(1):27-35.
52. Pereira R, Lima D, Giorgi MCC, Marchi GM, Aguiar FHB. Evaluation of bond strength, nanoleakage, and marginal adaptation of bulk-fill composites submitted to thermomechanical aging. J Adhes Dent. 2019;21(3):255-64.
53. Ruengrungsom C, Burrow MF, Parashos P, Palamara JEA. Comprehensive characterisation of flexural mechanical properties and a new classification for porosity of 11 contemporary ion-leaching dental restorative materials. J Mech Behav Biomed Mater. 2021;121:104615.
54. Daabash R, Alshabib A, Alqahtani MQ, Price RB, Silikas N, Alshaafi MM. Ion releasing direct restorative materials: key mechanical properties and wear. Dent Mater. 2022;38(12):1866-77.
55. Hughes KO, Powell KJ, Hill AE, Tantbirojn D, Versluis A. Delayed photoactivation of dual-cure composites: effect on cuspal flexure, depth-of-cure, and mechanical properties. Oper Dent. 2019;44(2):e97-e104.
56. Wierichs RJ, Rupp K, Meyer-Lueckel H, Apel C, Esteves-Oliveira M. Effects of dentifrices differing in fluoride content on remineralization characteristics of dentin *in vitro*. Caries Res. 2020;54(1):75-86.
57. Fu Y, Ekambaram M, Li KC, Zhang Y, Cooper PR, Mei ML. *In vitro* models used in cariology mineralisation research-a review of the literature. Dent J (Basel). 2024;12(10):323.
58. Chen H, Zhang J, Hill R, Baysan A. Evaluation of toothpastes for treating root carious lesions - a laboratory-based pilot study. BMC Oral Health. 2024;24(1):484.
59. Takagi S, Liao H, Chow LC. Effect of tooth-bound fluoride on enamel demineralization/ remineralization *in vitro*. Caries Res. 2000;34(4):281-8.
60. Lynch RJ, Mony U, ten Cate JM. Effect of lesion characteristics and mineralizing solution type on enamel remineralization *in vitro*. Caries Res. 2007;41(4):257-62.
61. Birant S, Gümüştaş B. The effect of thermal aging on microhardness and SEM/EDS for characterisation bioactive filling materials. BMC Oral Health. 2024;24(1):1142.
62. Farooq I, Bugshan A. The role of salivary contents and modern technologies in the remineralization of dental enamel: a narrative review. F1000Res. 2020;9:171.

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Study on the Relationship Between Nutritional Awareness and Dietary Behavior of Thai Muslim Older Adults in Watthana District, Bangkok

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Abstract

Objectives: This study investigates the relationship between nutritional awareness and dietary behavior among Thai-Muslim older adults in the Watthana district of Bangkok.

Methods: Utilizing a cross-sectional design, we sampled 400 individuals aged 60 and above (mean age = 68.70±5.64 years) through simple random sampling across five communities. The study is framed within the Mixed Model of Emotional Intelligence, focusing on emotional awareness, accurate self-assessment, and self-confidence as key components. Data were collected through structured interviews and analyzed using Pearson's correlation and multiple linear regression techniques.

Results: Pearson's correlation analysis revealed significant relationships between emotional awareness, accurate self-assessment, self-confidence, and dietary behavior, with correlation coefficients of 0.29, 0.55, and 0.57, respectively (p<0.01). Multiple linear regression analysis further identified that the constant (β = 2.00), accurate self-assessment (β=0.21, p<0.01), and self-confidence (β=0.22, p<0.01) were significant predictors of improved dietary behaviors.

Conclusions: The findings of this study underscore the critical role of emotional awareness, accurate self-assessment, and self-confidence in shaping dietary behaviors among older adults. These factors were significantly associated with healthier dietary patterns (p<0.01). Based on these results, it is recommended that targeted educational interventions aimed at enhancing emotional intelligence and self-assessment skills could play a pivotal role in improving dietary behaviors and overall health outcomes for older adults in this population.

Keywords: awareness, behaviors, dietary, emotional, nutritional

Introduction

Good nutrition is essential for maintaining health and enhancing quality of life among older adults. Educating this demographic and encouraging the application of sound nutritional principles in daily life can significantly reduce the risk of chronic diseases[1], strengthen the immune system[2], preserve muscle mass[3], and improve brain function and nervous system health.[4] Furthermore, adequate nutrition is critical in preventing malnutrition, a prevalent concern among older adults.[5] Therefore, understanding and adhering to proper nutritional practices is crucial in older adults' healthcare.

Muslim older adults, however, face distinct nutritional challenges that can impact both their health and overall well-being. A key issue is the difficulty in accessing halal food, which adheres to specific Islamic dietary standards. This limitation can lead to nutrient deficiencies.[6] Additionally, cultural and traditional food practices among Muslims may sometimes conflict with optimal nutritional guidelines, potentially affecting dietary behavior.[7] Many Thai-Muslim older adults also face a range of chronic health conditions, including diabetes, hypertension, and cardiovascular disease, which require specific dietary modifications for effective management.[8] These challenges are consistent with findings from previous studies conducted in Thailand.[9,10]

Similar studies in other global contexts have highlighted comparable concerns. For instance, research by Norman *et al*.,[11] in Germanyfound that older adults with limited access to food were more likely to experience malnutrition and associated health problems. Likewise, Nazri *et al*.,[12] reported that insufficient dietary intake significantly increased the risk of chronic diseases among older adults with low socioeconomic status. Leung *et al*.,[13] also demonstrated that restricted access to nutritious food correlates with higher rates of malnutrition and related health issues.

A cross-sectional descriptive study by Rungsiyanont and Sakoolnamarka (2023) examined older adult populations in Samut Prakan[14] and Nakhon Nayok.[15] Their findings highlighted those personal factors such as income, education level, and cohabitation with family members positively influenced dietary behaviors. In a related study, Vaudin *et al*.,[16] explored the role of awareness and the use of nutrition information in predicting diet quality among older adults. Their research emphasized that accurate self-assessment and heightened nutritional awareness are key factors in making healthier food choices.

Furthermore, emotional awareness-the ability to recognize and understand one's own emotions-along with self-assessment and self-confidence, plays a critical role in shaping dietary behavior. These psychological factors influence motivation, attitudes, and beliefs about food, which ultimately guide healthier eating patterns.

Emotional awareness refers to the ability to identify and comprehend one's emotions, while accurate self-assessment involves objectively evaluating one’s strengths and weaknesses. Confidence, in this context, is the belief in one’s capacity to successfully navigate tasks and challenges. Dietary behavior encompasses the choices and patterns individuals adopt concerning food intake and eating habits. Research indicates that these psychological components significantly impact older adults' dietary decisions by shaping their motivation, attitudes, and beliefs about nutrition.

To support healthier eating practices, the "Nine Dietary Guidelines"[17] were introduced by the Nutrition Division of the Department of Health, Ministry of Public Health, and the Institute of Nutrition at Mahidol University. These guidelines provide a structured framework to assist individuals in making more informed dietary choices.

The findings of these studies can be further contextualized through Daniel Goleman’s Emotional Intelligence framework[18], which underscores the importance of self-awareness and emotional understanding in shaping individual behaviors and decision-making. Goleman’s model outlines three key components: 1) Emotional Awareness-he ability to recognize and understand one’s own emotions and those of others; 2) Accurate Self-Assessment-the realistic evaluation of one’s strengths and weaknesses; and 3) Self-Confidence—the belief in one’s abilities to succeed.

The research team is also interested in exploring underrepresented ethnic groups in Thailand. With appropriate funding, they plan to begin their study with ethnic populations in Bangkok. According to the National Statistical Office[19], the Thai-Muslim population aged 15 and older in Thailand is 2,731,810, with approximately 338,219 residing in Bangkok. These communities are concentrated along the 55-mile Saen Saeb Canal, which connects the city to the Bang Pakong River. The area

is home to several important waterways, including the Maha Nak Canal and both the upper and lower Saen Saeb Canals, where Muslim communities have established mosques, cemeteries, and Islamic schools since the reign of King Rama III, contributing to the historical development of the canal.

The lower Saen Saeb Canal is a major waterway in the Wattana district, which is home to a significant Thai-Muslim community. The area contains six mosques, and the population of Thai Muslims over the age of 60 is estimated to be approximately 3,700, according to unofficial community registry data. The community preserves traditional lifestyles across 16 neighborhoods, reflecting their rich cultural heritage and practices.

Objective

The objective of this study was to investigate the relationship between nutrition awareness and the dietary behavior of Thai-Muslim older adults in the Watthana district of Bangkok.

Importance of the study

Thai-Muslim older adults play a vital role in strengthening and sustaining the Thai-Muslim community. Addressing their nutritional challenges can create a solid foundation for improving their quality of life and health in a sustainable manner. The findings from this research will provide valuable insights for developing nutrition programs and policies that are culturally and religiously aligned with the needs of Thai-Muslim older adults. This approach will not only enhance the relevance of health interventions but also improve the long-term effectiveness of healthcare for older adults in this community.

Materials and Methods

Study design

This study was a cross-sectional study and has been approved by the Ethics Committee for Research on Humans and Animals, Srinakharinwirot University, with the approval number SWU-EC096/2566E, prior to data collection.

Sample size calculation

The study population consisted of older adults' individuals aged 60 years or older who have resided in the area for no less than six months, both male and female, who can communicate and remember normally. According to the 2017 data from the Department of Health Strategy and Environmental Health (SIA), there are 16,278 older adults' individuals in the Watthana district, Bangkok. The sample size was calculated using the formula by Krejcie & Morgan (1970)[20], resulting in a sample size of 374 individuals.

Sampling method

Simple random sampling was conducted across 16 communities, leading to the selection of 5: Mee Suwan Sam, Cham Chan, Klong Tan Bridge, Bandon Mosque, and Ban Sam In Development. A sample size of 374 was deemed necessary, with each selected community announcing a call for volunteers to recruit 80 participants from their members. To account for potential non-responses, the total sample size was increased to 400.

Data collection procedure

Before data collection, the researcher trained interviewers on data collection methods and the use of the interview form. A preliminary test was conducted with a group similar to the sample to refine the questionnaire. Data collection involved direct interviews with the sample, coordinated through public health volunteers (PHVs) in Watthana district. The researcher, accompanied by village PHVs, conducted 20-minute interviews. The questionnaire was designed using culturally appropriate language and terminology to ensure participants fully understood and accurately responded. Questions included foods and dietary behavior specific to the Thai-Muslim culture, such as halal dietary laws and traditional foods, ensuring relevance and accuracy.

Instruments

Data collection utilized an interview questionnaire developed in Thai, divided into three main sections:

Personal factors: Closed-ended questions were used to gather basic general information such as gender, highest education level, family income, and living arrangements with family (5 items).

Nutrition awareness: The Nutrition Awareness questionnaire was based on Goleman's Mixed Model of Emotional Intelligence Theory[18], adapted from research by Sakoolnamarka and Rungsiyanont.[14,15] The questions

focus on three key areas: Emotional Awareness (10 items), Accurate Self-Assessment (9 items), and Self-Confidence (7 items). Each item used a scoring criterion with 5 levels as follows: Very Much = 5, Much = 4, Moderate = 3, Little = 2, Very Little = 1, Not at All = 0. For negatively worded questions, the scores will be reversed, with the negative questions marked with an asterisk (*).

Dietary behavior: The dietary behavior questionnaire was designed to assess behaviors aligned with the "Nine Food-Based Dietary Guidelines" from the Department of Nutrition, Ministry of Public Health, and the Institute of Nutrition at Mahidol University (1999).[17] This ensured a relevant and thorough evaluation of the sample's dietary behavior. Culturally appropriate language and terminology were used to help participants fully understand the questions, which included foods and dietary practices specific to Thai-Muslim culture, such as halal dietary laws and traditional foods, enhancing the assessment's relevance and accuracy. The questionnaire consisted of 12 items, including 6 items reflecting positive behaviors and 6 items reflecting negative behaviors. It measured the frequency of dietary behavior among older adults over a specified period.

The questions measure the frequency of consumption with 10 items reflecting positive behavior. The scoring criteria are as follows: Consumed Daily (7 days/week) = 5, Consumed Frequently (4-6 times/week) = 4, Consumed Moderately (1-3 times/week) = 3, Consumed Rarely (1-3 times/month) = 2, Consumed Very Rarely (less than once/month) = 1, Never Consumed = 0. For negatively worded questions, the scores will be reversed. with the negative questions marked with an asterisk (*).

The scoring interpretation for nutrition awareness and dietary behavior consists of 5 levels as follows: Very Low=0-1, Low=1.01-2, Moderate=2.01-3, High=3.01-4, Very High=4.01-5

Data analysis

The normal distribution of the mean scores representing nutritional awareness and dietary behavior was tested using Skewness and Kurtosis statistics. Nutritional awareness scores for all three aspects showed Skewness and Kurtosis values between -1.00 and 1.00, indicating a normal distribution.

Statistical methods used:

Descriptive statistics: Percentage: Used to describe the proportion of the sample in each category of data.

Mean: Used to calculate the average scores for each item, providing an overview of the data.

Inferential statistics:

Independent T-test: Used to test differences in mean scores between independent groups, such as gender, living with family and dietary behavior.

One-Way ANOVA: Used to test differences in mean scores between groups with more than two categories, such as highest education level, total family income, and dietary behavior.

Pearson correlation: Used to analyze the relationship between two variables, specifically the relationship between the three components of nutritional awareness and dietary behavior.

Multiple regression analysis: Used to analyze the relationship between multiple independent variables and the dependent variable to study the impact of several independent variables on the dependent variable using the multiple regression equation.

Data quality control

The internal consistency reliability of the questionnaire was assessed. Content validity and appropriateness of wording were verified by three experts, ensuring an Index of Item-Objective Congruence (IOC) of at least 0.50 for all items. Reliability was further tested by administering the questionnaire to a similar population aged 50-59 years, involving 30 individuals. The Cronbach's alpha coefficient for each section was greater than 0.70 indicating good reliability. Additionally, trained interviewers underwent a calibration process to ensure consistent administration of the questionnaire. This included standardized training sessions to familiarize them with the content and structure, enabling effective and uniform interviews.

Results

From the sample of 400 older adults individuals aged 60 years and above 154 were male (38.5%) and 246 were female (61.5%), with an average age of 68.70 (±5.64 years) The majority had a highest education level of primary school (218 individuals, 54.5%), and most had a monthly income between 6,000-10,000 THB (144 individuals, 36.0%). Additionally, 364 individuals (91.0%) were living with family members, as shown in Table 1.

Table 1: Personal factors of the population.

Demographic data	Amount	Percentage (%)
Gender		
Male	154	38.5
Female	246	61.5
Education		
Under primary school	36	9.0
Primary school	218	54.5
Secondary school	68	17.0
High school /Certificate	48	12.0
Bachelor's degree or above	30	7.5
Family income		
Under 6,000 THB	108	27.0
6,000 - 10,000 THB	144	36.0
10,001 -25,000 THB	94	23.5
25,001 - 50,000 THB	52	13.0
50,000 THB or above	2	0.5
Living status		
Live alone	36	9.00
Live with others	364	91.0
Total	400	100

Nutritional awareness

1.1 Emotional awareness

The survey results indicated that the overall emotional awareness score was at a moderate level (2.99 points), with a high level of emotional awareness in several aspects. Respondents expressed that they loved to eat with others (3.78 points), were not guilty about finishing their drink after a meal at a restaurant (3.47 points), and felt alright about eating unhealthy food that they liked (3.11 points). They also felt guilty when eating unhealthy food (3.04 points) but did not feel guilty about having leftover meals (3.02 points). At a moderate level, they felt alright about not eating meals on time (2.88 points), felt good about drinking soda when they wanted or were thirsty (2.80 points), and did not feel guilty about not finishing their food (2.75 points). Additionally, they felt good about eating as much as they wanted (2.72 points) and did not feel guilty for eating junk food (2.37 points), as detailed in Table 2.

Table 2: Emotional awareness in population.

Items	mean	SD	Interpret
You are not guilty for not finishing a meal.*	2.75	1.05	moderate
You feel good when finishing drinks after a meal.	3.47	1.13	high
It's alright not to eat the meal on time.	2.88	1.15	moderate
You are not feeling guilty after consuming unhealthy food.*	3.04	1.21	high
You are not feeling guilty for having a leftover meal.*	3.02	1.35	high
You feel good when get to eat as much as you like.	2.72	1.34	moderate
You are contented when having soft drinks as when you feeling thirsty/hungry.	2.80	1.63	moderate
You love to eat with others.	3.78	1.44	high
It's alright to eat unhealthy food which you like.*	3.11	1.47	high
You are not feeling guilty for eating junk foods.*	2.37	1.30	moderate
Total	**2.99**	**1.31**	**moderate**

1.2 Accurate self-assessment

The survey results indicated that the overall accurate self-assessment score was at a high level (3.46 points). The older adults had the highest level of accurate self-assessment in their ability to gauge their own fullness while eating (4.10 points). Following closely, they were able to evaluate their ability to handle spicy food (3.91 points) and assess the amount of nutritious food they consumed in a day (3.88 points). They could also gauge the amount of non-nutritious food they consumed in a day (3.70 points). At a moderate level, they estimated the energy they received after eating (2.82 points) and, even if they knew their blood sugar was high, they would still eat their favorite dessert if it was included in the meal (2.75 points), as detailed in Table 3.

1.3 Self-confidence

The survey results revealed that the overall self-confidence score was at the highest level (4.07 points). The highest level of self-confidence among the older adults was in their ability to prepare appropriate meals for their family members (4.27 points). They were also highly confident that the food they ate every day was beneficial (4.16 points), that they could confidently choose suitable menu items for themselves (4.15 points), and that they could confidently share their knowledge about the benefits and drawbacks of various foods with others (4.10 points). Closely following, they expressed strong confidence in the belief that they should eat a large number of vegetables and fruits daily to ensure sufficient fiber for good health (3.95 points). They also believed they could control the amount of food they consumed each day (3.93 points) and were confident that the energy they received from their daily food intake was appropriate (3.90 points), as detailed in Table 4.

Dietary behavior

The assessment of dietary behavior was divided into positive and negative questions to evaluate good and poor dietary behavior, respectively. Negative behavior scores were reversed for the calculation of average scores. Therefore, a higher score indicates the presence of healthy dietary behavior, while a lower score indicates unhealthy dietary behavior. The results showed that the overall

Table 3: Accurate self-assessment in population.

Items	mean	SD	Interpret
You will not stop consuming until you feel full even though you have already had a lot.*	3.18	1.07	high
You do realize that you are not able to chew on hard food.	3.33	1.34	high
You eat tempting desserts even when you recognize that it is not good for your health.*	2.75	0.95	moderate
You are willing to eat dislike vegetables.	3.47	1.27	high
You are able to recognize when you are full.	4.10	0.91	highest
You do recognize your ability to consume spicy food.	3.91	1.09	high
You are able to indicate the healthy food portions in your daily consumption.	3.88	1.12	high
You are able to indicate the unhealthy food portions in your daily consumption.	3.70	1.15	high
You are able to estimate the energy from each meal.	2.82	1.14	moderate
Total	**3.46**	**1.12**	**high**

Table 4: Self-confidence in population.

Items	mean	SD	Interpret
You assure that you have ability to make healthy food choices for yourself.	4.15	0.93	highest
You assure that you have ability to make healthy food suggestions for your family.	4.27	0.81	highest
You assure that you eat with confident that your meals are healthy.	4.16	0.81	highest
You assure that you consume enough fruits and vegetables on a daily basis.	3.95	0.84	high
You assure that you have ability to guide others on risk and benefits of their meals.	4.10	1.05	highest
You assure that you have ability to control food portions in each meal.	3.93	1.11	high
You mistrust of the food taste which was cooked by others.*	3.90	1.04	high
Total	**4.07**	**0.94**	**highest**

dietary behavior score was at a high level (3.62 points). The older adults had a low level of consumption of whole grains and whole grain products (1.73 points). They had a high level of consumption of vegetables root vegetables, crunchy snacks (chips, potato chips, dried fruits), protein foods, rich cheesy, mellow or savory foods, a variety of foods from each of the five food groups, more than three meals a day, desserts and baked goods, and drinks like soda and soft drinks (3.99, 3.57, 3.55, 3.51, 3.44, 3.37, 3.36, and 3.35 points, respectively). The highest levels of behavior were seen in consuming properly washed and cooked food, drinking clean water from trustworthy sources, and drinking alcoholic beverages (4.72, 4.45, and 4.45 points, respectively), as detailed in Table 5.

Subsequently, the personal factors data were analyzed alongside the average scores representing nutritional awareness in three areas: emotional awareness, accurate self-assessment, and self-confidence, as well as the dietary behavior of the older adults. The analysis was conducted using independent t-test and One-way ANOVA. The results indicated that the personal factors of the older adults in this study did not significantly affect dietary behavior, Similarly, the analysis of personal factors against the average scores for the three areas of nutritional awareness and dietary behavior using independent t-test and One-way ANOVA found no significant relationship between personal factors and the dietary behavior of the older adults.

The data were then analyzed to determine the relationships between the variables using Pearson's Correlation. The average scores representing personal awareness of nutrition in the three areas-emotional awareness, accurate self-assessment, and self-confidence-and the dietary behavior of the older adults were examined. The analysis revealed that all three aspects of nutritional awareness were significantly correlated with the dietary behavior of the older adults at the $p<0.01$ level. The correlation coefficients (r) ranged from 0.29 to 0.57, indicating a low to moderate positive correlation, as shown in Table 6.

The statistical analysis indicates that the three sub-

Table 5: Dietary behavior in population.

Items	mean	SD	Interpret
Eat desserts; Thai traditional dessert, cake and pastries*.	3.36	1.08	high
Eat more than 3 meals a day.*	3.37	1.53	high
Drink Soda and soft drink.*	3.35	1.15	high
Drink alcohol beverages.*	4.45	0.95	highest
Eat vegetables and root vegetables.	3.99	1.07	high
Eat crunchy snacks; chips, potato chips, dried fruits*.	3.57	1.25	high
Eat variety of foods that provide the five major nutrients.	3.44	1.00	high
Eat whole grains and whole grain products.	1.73	1.53	low
Eat protein foods; egg(s), nuts, meat.	3.55	1.06	high
Eat rich cheesy, mellow or/and savory food.*	3.51	1.02	high
Drink water and drinks from trustworthy sources.	4.45	0.70	highest
Eat properly washed and cooked food.	4.72	0.58	highest
Total	**3.62**	**1.08**	**high**

Table 6: The relationship between nutritional awareness and dietary behavior, analyzed using Pearson's correlation to identify influencing factors within the population.

		Emotional Awareness	Accurate Self-assessment	Self-confidence	Dietary Behavior
Emotional awareness	Pearson Correlation Sig (2-tailed)	1	0.41**	0.46**	0.29**
Accurate self-assessment	Pearson Correlation Sig (2-tailed)	0.41**	1	0.67**	0.55**
Self-confidence	Pearson Correlation Sig (2-tailed)	0.46**	0.67**	1	0.57**
Dietary behavior	Pearson Correlation Sig (2-tailed)	0.29**	0.55**	0.57**	1
	N	400	400	400	400
** $p<0.01$					

areas of nutritional awareness are significantly related to the dietary behavior of the older adults. Thus, it can be concluded that these three sub-areas of nutritional awareness are significantly associated with the dietary behavior of older adults' individuals in Watthana district, Bangkok. Specifically, emotional awareness, accurate self-assessment, and self-confidence are positively correlated with better dietary behavior. This suggests that higher levels of nutritional awareness among the older adults are likely to result in better dietary behavior.

The mean difference test across different groups did not show statistically significant results.

The impact of certain factors on dietary behavior is analyzed using the following regression equation: $Y=\beta0+\beta1X1+\beta2X2+\beta3X3+\epsilon$. Where:

Y = Dietary behavior of Thai-Muslim older adults in Wattana district.

β 0 = Intercept (the value of Y when all independent variables are zero) = 2.00

β1, β2, β 3 = Regression coefficients of the independent variables

X 1 = Emotional awareness, X 2 = Accurate self-assessment, X3= Self-confidence, ϵ = Error term (unexplained variation)

β 1 (Emotional awareness) = 0,β 2 (Accurate self-assessment) = 0.21, β 3 (Self-confidence) = 0.22.

A multiple linear regression equation for the dietary behavior of Thai-Muslim older adults in the Watthana district of Bangkok is =2.00+(0.21×Accurate self-assessment) +(0.22×Self-confidence)+ϵ

These results indicate that higher levels of nutritional awareness are associated with better food consumption behaviors among the older adults. The analysis supports the alternative hypothesis (HA), demonstrating that nutritional awareness significantly influences the food consumption behaviors of the older adults in Watthana district, Bangkok.

Discussion

This study aimed to explore the relationship between nutritional awareness and dietary behavior in Thai-Muslim older adults, demonstrating that nutritional awareness significantly influenced dietary behavior across all measured aspects at the 0.01 level. These findings align with global literature, such as Chin *et al*.,[21] which also found that older adults with greater nutritional knowledge made healthier food choices. Consistent with these studies, our findings show that greater self-assessment accuracy was linked to increased confidence in food choices, contributing to healthier dietary behaviors. This highlights the critical role of nutritional knowledge in shaping dietary habits among older adults.

However, our study deviates from other research, such as that by Woodruff and Hanning (2011)[22], which highlighted the role of family meals in promoting healthier dietary behaviors. In this study, no such relationship was observed among the Thai-Muslim older adult population. This absence could be attributed to cultural differences; while family meals are a common social practice in some cultures, the dietary habits and social dynamics of Thai-Muslim older adults may not emphasize family meal settings in the same way. As such, interventions targeting this population may need to explore other strategies more suited to their social and cultural contexts.

Further comparison with studies from Thailand's Eastern ($p<0.01$)[23] and Central ($p<0.01$)[24] regions reveals that the Thai-Muslim older adults exhibited stronger correlations between nutritional awareness and dietary behavior. Specifically, the correlation between self-assessment accuracy and dietary behavior was notably higher in the Thai-Muslim group (r=0.55) than in the Eastern (r=0.24) and Central (r=0.48) groups. This finding suggests that self-assessment plays a more prominent role in guiding healthier dietary behaviors in the Thai-Muslim community. Additionally, the Thai-Muslim group exhibited

Table 7: Result summary of multiple linear regression analysis.

Variable	Unstandardized Coefficient (β)	Std. Error	Standardized Coefficient (beta)	t	sig
Constant	2.00	0.15		13.13	$p<0.01$
Accurate self-assessment. (X2)	0.21	0.44	0.34	4.90	$p<0.01$
Self-confidence. (X3)	0.22	0.54	0.30	4.03	$p<0.01$

a stronger correlation between confidence in food consumption and dietary behavior (r=0.57) compared to the Eastern (r=0.29) and Central (r=0.08) groups, suggesting that greater self-efficacy in food choices is a key factor in promoting healthier eating patterns. These results indicate that cultural and community-specific factors, including the religious and social environment of Thai-Muslim older adults, may enhance self-awareness and self-confidence in making dietary decisions.

The relationship between confidence in food consumption and emotional awareness was also stronger in the Thai-Muslim group (r=0.46) than in the Eastern (r=0.10) and Central (r=0.08) groups. This finding implies that emotional awareness plays a significant role in food-related decision-making for Thai-Muslim older adults. Emotional awareness, the ability to recognize and manage emotions related to food choices, may support the development of a healthier, more balanced approach to eating. It is possible that this emotional dimension is more pronounced in this population, due to cultural or religious factors that emphasize mindfulness and self-control in food consumption. In terms of overall dietary behavior, the Thai-Muslim group demonstrated better dietary outcomes, with an average score of 3.62 compared to the Eastern (3.22) and Central (3.06) groups.[23,24]

This suggests that, despite facing similar challenges in managing health outcomes, Thai-Muslim older adults, due to their higher levels of nutritional awareness, self-assessment, and emotional awareness, tend to exhibit healthier dietary practices. However, despite these positive correlations, some health challenges persist among this group. These challenges are likely due to the inconsistency between nutritional knowledge and actual food practices. For example, although participants showed high awareness, issues such as portion control and selecting foods high in fat and sugar may undermine the benefits of their nutritional knowledge. Additionally, factors such as physical activity levels, exercise habits, and genetic predispositions may also contribute to suboptimal health outcomes despite better dietary behaviors.

The correlation analysis in this study indicated that all aspects of nutritional awareness-emotional awareness, self-assessment, and confidence in food consumption-were significant predictors of dietary behavior. However, in the multiple linear regression analysis, emotional awareness did not have a significant impact on dietary behavior. This suggests that while emotional awareness may be important in correlating with dietary behaviors, its influence might be more indirect compared to self-assessment and self-confidence. Given this, health programs targeting Thai-Muslim older adults should prioritize enhancing skills related to accurate self-assessment and boosting self-confidence in food choices, as these factors showed the strongest influence on dietary behaviors.

Improving self-assessment skills could help individuals recognize and correct unhealthy eating patterns, while enhancing self-confidence could empower older adults to make informed food choices, even in the face of dietary temptations or challenges. Incorporating these areas into health interventions could potentially lead to more sustainable improvements in dietary practices, thereby enhancing overall well-being and health outcomes for Thai-Muslim older adults.

In conclusion, while Thai-Muslim older adults exhibit strong nutritional awareness and healthy dietary behaviors, challenges remain in translating knowledge into consistent practice. By focusing on improving self-assessment and self-confidence, targeted interventions can be designed to support better dietary outcomes in this community. These interventions should be culturally sensitive and reflect the unique dietary patterns, religious practices, and social dynamics of the Thai-Muslim older adult population. By doing so, healthcare providers can enhance the long-term effectiveness of nutrition programs and contribute to the improvement of health outcomes in this demographic

Recommendations for improving dietary behavior among Thai-Muslim older adults

To enhance dietary behavior, focus on increasing nutritional awareness through educational programs that teach older adults to assess and improve their dietary choices. Workshops on nutrition, meal planning, and balanced diets can empower them to make healthier decisions. Building self-confidence in food choices can be supported through community initiatives and positive reinforcement, such as encouraging the exploration of new foods and sharing dietary experiences. By prioritizing accurate self-assessment and self-confidence, a supportive environment can be created, fostering healthier choices and improving quality of life.

Limitations

While the sample size of 400 in Bangkok is substantial, it may not fully represent the broader Thai-Muslim elderly population, potentially overlooking sub-groups with varying socio-economic or educational backgrounds. The cross-sectional design limits causal inferences, highlighting the need for longitudinal studies for deeper insights. Additionally, reliance on self-reported data may introduce biases, as responses reflect participants' self-assessment rather than direct observation. Lastly, the findings are specific to Thai-Muslim older adults in the Watthana district, limiting their generalizability to other populations or regions.

Recommendations for further study

Future studies should expand sample size and diversity by using stratified random sampling based on demographic factors to improve representativeness. Longitudinal designs are needed to track changes in nutritional awareness and dietary behavior over time, helping to establish causal relationships. Incorporating qualitative methods, such as interviews, can offer deeper insights into the factors influencing dietary choices. Additionally, comparative studies across different ethnic groups in Thailand, including indigenous communities and migrant workers, will help identify unique challenges and effective strategies, ensuring inclusive and equitable health interventions.

Conclusions

The factors of nutritional awareness-emotional awareness, accurate self-assessment, and self-confidence-were all found to be significantly correlated with dietary behavior among Thai-Muslim older adults ($p<0.01$). These findings suggest that enhancing nutritional awareness in these key areas may lead to improved dietary choices, thereby promoting healthier eating patterns and contributing to the overall well-being of Thai-Muslim older adults.

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References

1. Sacks FM, Lichtenstein AH, Wu JH.Y, Appel LJ, Creager MA, Kris-Etherton PM, *et al*. Dietary fats and cardiovascular disease: a presidential advisory from the American Heart Association. Circulation. 2017;136(3):e1-e23.
2. Lesourd, B. Nutritional factors and immunological ageing. Proceedings of the Nutrition Society. 2006;65(3):319-25.
3. Houston DK, Nicklas BJ, Ding J, Harris TB, Tylavsky FA, Newman AB, *et al*. Dietary protein intake is associated with lean mass change in older, community-dwelling adults: the health, aging, and body composition (Health ABC) study. Am J Clin Nutr. 2008;87(1):150-55.
4. Morris MC, Tangney CC, Wang Y, Sacks FM, Bennett DA, Aggarwal NT. MIND diet associated with reduced incidence of Alzheimer's disease. Alzheimers Dementia. 2015;1(9):1007-14.
5. Damayanthi HDWT, Moy FM, Abdullah KL, Dharmaratne SD. Prevalence of malnutrition and associated factors among community-dwelling older persons in Sri Lanka: a cross-sectional study. BMC Geriatrics. 2018;18(1):199.
6. Ajrouch KJ. Caring for aging Muslim families: A needs assessment [Internet]. Institute for Social Policy and Understanding. Available from:https://www.ispu.org/wp-content/uploads/2016/12/Caring-for-Aging-Muslim-Families-full-report.pdf
7. Huda. (2019, April 17). Halal and haram: The Islamic dietary laws. Islamic rules about eating and drinking [Internet]. Learn Religions. 2019 Apr 17 [updated 2019 Apr 17; cited 2024 Jan 24]. Available from: https://www.learnreligions.com/islamic-dietary-law-2004234
8. Phaitrakoon J, Rassameepong S, Jirarattanawanna N, Sukonvattanaamorn S, Boontem P, Chulakarn N. Assessment of dietary and exercise behavior of aging Muslims in Thailand. J Islam Stud Cult. 2017;5(1):16-23.
9. Sukchan P, Srisawa S, Asanasa K, Konandana P, Ding Z, Jaeuseng A. The relationship of morbidity or comorbidity and health behaviors among the Muslim elderly in Narathiwat: a community cross-sectional study. PNUJR. 2022;14(3):121-39.
10. Lundberg PC, Thrakul S. Diabetes type 2 self-management among Thai Muslim women. J Nurs Healthcare Chronic Illness. 2011;3(1):52-60.
11. Norman K, Haß U, Pirlich M. Malnutrition in older adults—recent advances and remaining challenges. Nutrients. 2021;13(8):2764.
12. Nazri NS, Vanoh D, Leng SK. Malnutrition, low diet quality and its risk factors among older adults with low socio-economic status: a scoping review. Nutr Res Rev. 2021;34(1):107-16.
13. Leung CW, Insolera NE, Wolfson JA. Trends in recurring and chronic food insecurity among US families with older

adults. JAMA Health Forum. 2024;5(3):e235463.
14. Rungsiyanont S, Sakoolnamarka S. Correlation between nutrition awareness and food consumption behaviors of elderly in Samut Prakarn province. J Public Health Epidemiol. 2023;15(2):55-63.
15. Sakoolnamarka S, Lawprasert K, Larpjitkusol S, Srikan T, Chuayboon S, Rungsiyanont S. Correlation between nutritional awareness and food consumption behaviors of the elderly in Nakhon Nayok province. SWU Dent J. 2021;14(1):64-79.
16. Vaudin A, Wambogo E, Moshfegh A, Sahyoun NR. Awareness and use of nutrition information predict measured and self-rated diet quality of older adults in the USA. Public Health Nutr. 2021;24(7):1687-97.
17. Healthy diet for elderly. Guideline for food consumption to make good health in Thai elderly [Internet]. 2017 Dec 15 [updated 2017 Dec 15; cited 2021 Sep 20]. Available from: http://nutrition.anamai.moph.go.th/images
18. Goleman D. Emotional intelligence: Why it can matter more than IQ. London, UK: Bloomsbury Paperbacks; 1995.
19. National Statistical Office. Number of Muslims aged 13 and older classified by religious activity. 2021 Jun 30 [updated 2021 Jun 30; cited 2024 Oct 11]. Available from: https://catalogapi.nso.go.th/api/index?table=OS_04_0004_02&-format=csv
20. Krejcie RV, Morgan DW. Determining sample size for research activities. Educ Psychol Meas. 1970;30(3):607-10.
21. Chin S, Wong R, Hirani V, O'Leary F. Nutrition knowledge assessment tools for older adults and their carers: a scoping review. Nutr Res Rev. 2023; 36(2): 216-31.
22. Woodruff SJ, Hanning RM. The impact of family meals on diet and food behaviors. In V. Preedy, R. Watson, & C. Martin (eds.), Handbook of behavior, food and nutrition. Springer; 2011. p. 1615-26.
23. Rungsiyanont S, Sakoolnamarka SS. Correlation between nutritional awareness and food consumption of the elderly in the eastern part of Thailand. SWU Dent J. 2024;17(2):12-27.
24. Sakoolnamarka SS, Sorasun R. Correlation between nutritional awareness and food consumption of the elderly in the central of Thailand: a cross-sectional study. Ann Dent Oral Health. 2023;6(2):1051.

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The Accuracy of In-house Personalized Surgical Cutting Guide for Segmental Mandibulectomy: A Proof of Concept *In Vitro* Study

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Abstract

Objectives: Recently, the new computer-assisted surgery workflow for segmental mandibulectomy and reconstruction has been developed. The aim of this study was to evaluate the accuracy of in-house personalized surgical cutting guides for osteotomy on the mandible prior to reconstruction in *in vitro* study.

Methods: Twenty mandibular stereolithography underwent segmental mandibulectomy using the personalized surgical cutting guides. The virtual surgical plans with randomly generated anatomical defects were developed, and personalized surgical cutting guides were created. The stereolithography of mandible and personalized surgical cutting guides were manufactured with the three-dimensional printer using fuse deposition modelling. The segmental mandibulectomy was carried out using the personalized surgical cutting guide. The accuracy of osteotomy was determined using the superimposition between virtual surgical simulation data and scanned images of postoperative stereolithography in software. The error of osteotomy was evaluated in terms of absolute angular and distance deviation.

Results: After superimposition, the mean absolute angulation deviation of osteotomy was 1.3835±0.2357 degrees (95%CI; 1.3081-1.4588) and the mean absolute distance deviation of osteotomy was 1.2975±0.2907 mm (95%CI; 1.2045-1.3904).

Conclusions: The in-house personalized surgical cutting guides provided acceptable accuracy and feasibility for osteotomy on mandible. Further investigation in terms of clinical benefits is needed.

Keywords: computer assisted surgery, mandibular reconstruction, surgical cutting guide, three-dimensional printing, virtual surgical planning

Introduction

Segmental mandibulectomy is a surgical procedure that removes pathology from the mandible along with part of the surrounding tissue, resulting in bone continuity defects that must be restored. Mandibular reconstruction aims to restore the lower facial contour and abilities to masticate, swallow, and articulate. Numerous treatment options for mandibular reconstruction following segmental mandibulectomy have been proposed, including mandibular reconstruction plates with or without soft tissue flaps (no osseous reconstruction), nonvascularized bone grafts, and vascularized bone flaps.[1,2] Traditional mandibular reconstruction requires the surgeon's precision and skill for optimal osteotomy, bone segmentation, and modeling, based on intraoperative decisions. Subsequently, either intraoperatively bending plates or pre-bending plates on rapid prototype models are used to secure the remaining parts of the mandible and bone grafts.

The significance of surgical margins on both bone and soft tissue in the pathological ablation of the mandible has consistently generated substantial scientific interest. Traditionally, surgeons rely on inaccurate measurement techniques to establish safety margins during clinical procedures. Preoperative medical imaging has been used for planning the surgical margin without any tools transferring this information directly to surgery. Intraoperatively, the assessment of surgical margins depends on the surgeon's visualization, tactile perception, ability to estimate the tumor extension on the preoperative imaging, and anatomical understanding.

Computer-assisted surgery (CAS) is a procedure encompassing various types of technologies. This workflow is becoming increasingly prevalent globally and plays a crucial role in ablative and reconstructive surgery by enhancing the precision of osteotomy and graft positioning. Although computer-assisted mandibular reconstruction has shown increased efficiency in terms of accuracy and overall surgical outcomes[3,4], various barriers to its adoption have arisen worldwide. The in-house development of these workflows will enable institutions to design, manufacture, and conduct procedures under the CAS concept with their specific settings and limitations. The Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Chiang Mai University has been using CAS, consisting of virtual surgical planning and additive manufacturing, in various types of surgery.

Recently, the concept of an in-house CAS workflow has been developed for segmental mandibulectomy and mandibular reconstruction with nonvascularized iliac crest bone graft (NVIBG) under the limitations of the setting. The concept of this workflow consisted of computer-assisted planning of mandibulectomy and manufacturing of a personalized surgical cutting guide using a three-dimensional printer (only fuse deposition modeling). With the limitations of available software and additive manufacturing, the institute's surgeon still must pre-blend the mandibular reconstruction plate and intraoperatively segment or model NVIBG. Previous CAS workflows have used an additional surgical cutting guide at the donor site, allowing for segmentation and modeling of either fibular or iliac bone grafts, along with a patient-specific reconstruction plate, which are not the components of our CAS workflow. Moreover, the in-house personalized surgical cutting guide is newly designed, and its efficacy must be proven. Thus, this *in vitro* study aimed to evaluate the accuracy of in-house personalized surgical cutting guides in providing planned osteotomies in mandibular models, ensuring their reliability and feasibility.

Material and Methods

Study design

This *in vitro* study was conducted within the Oral and Maxillofacial Surgery Clinic, Faculty of Dentistry, Chiang Mai University. A surgical cutting guide and virtual surgical planning with mandibular stereolithography were randomly constructed from a set of cone-beam computed tomography (CBCT) images of a patient with a normal mandible, selected by the oral and maxillofacial radiologist. An overview of the study design is illustrated in Figure 1. The study design was approved by the Institutional Ethical Committee, Faculty of Dentistry, Chiang Mai University, Thailand (approval no. 39/2563).

Concept of in-house surgical cutting guide design

The surgical cutting guide was designed through virtual surgical planning in Mimics Research software (Materialise, Leuven, Belgium), aiming to perform a planned mandibular osteotomy and stabilize the remaining parts of the resected mandible in the original position by fixing a pre-bending reconstruction plate and modeling bone graft. This surgical cutting guide also eliminates

the need for intraoperative intermaxillary fixation. The surgical cutting guide consists of three components: (1) the base, (2) the cutting plane, and (3) the axial connector (Figure 2). The base part with a screw hole directly contacts the bony surface and serves as a guide to settle the surgical cutting guide in a predetermined position. This part extends to cover the remaining parts of the resected mandible, especially the inferior border, and leaves a space for the pre-bending reconstruction plate. The cutting plane part acts as a guide for positioning the surgical saw when performing the mandibular osteotomy, with spared space for a reconstruction plate placement. Lastly, the axial connecting part bridges two cutting plane parts across the defect.

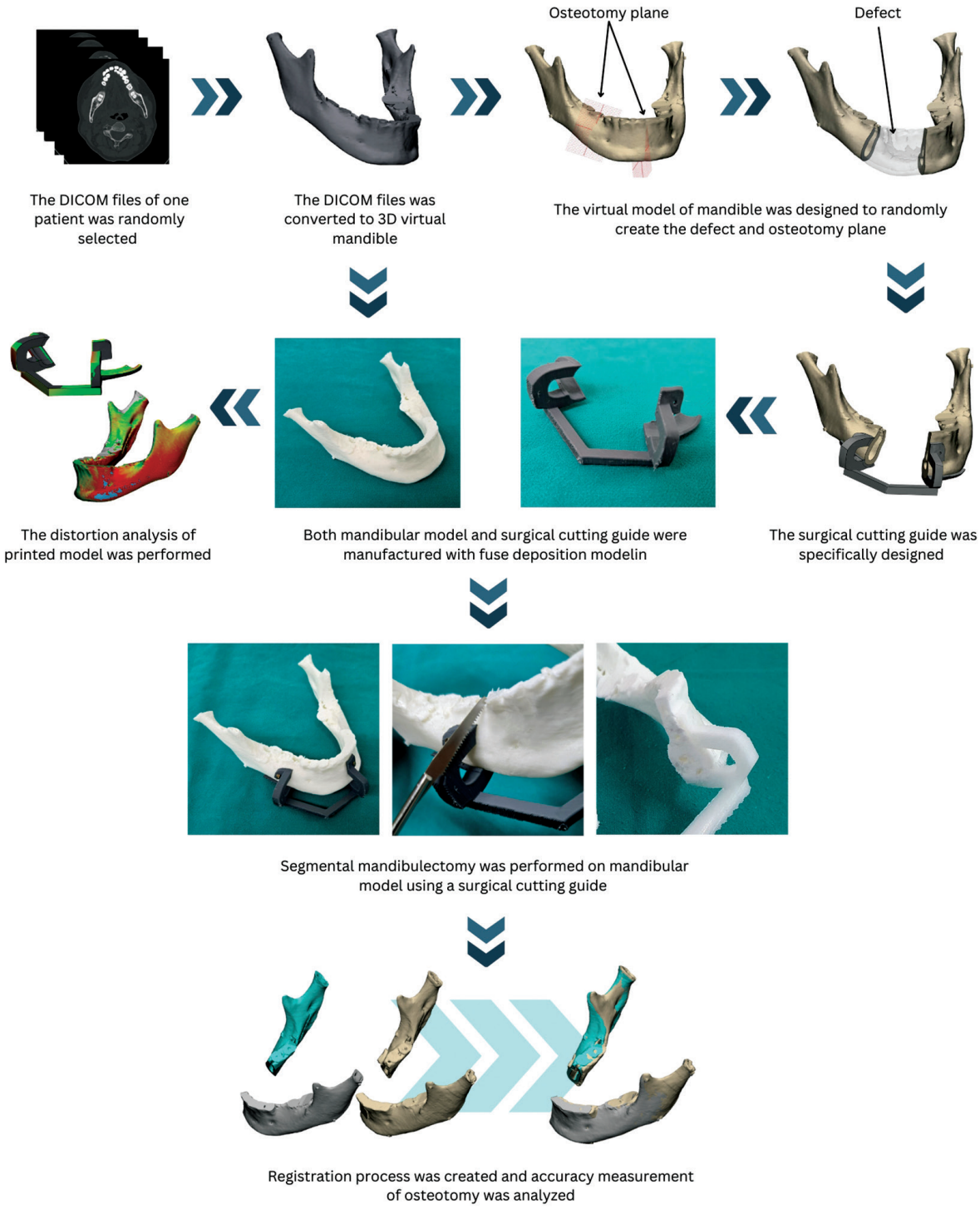

Figure 1: Study workflow of surgical simulation and personalized surgical cutting guide.

Surgical simulation and stereolithography manufacturing

The study workflow is presented in Figure 1. An image dataset of one patient with normal mandible morphology was randomly selected from the patients who obtained CBCT images involving the mandible using ORTHOPHOS XG 3D (Dentsply Sirona, New York, NY, USA) at 84 kV, 10 mA, and a 0.16-mm slice thickness. The CBCT images were exported in a Digital Imaging and Communications in Medicine (DICOM) format and imported into Mimics Research software V.20 (Materialise, Leuven, Belgium) to generate a three-dimensional (3D) virtual model of the mandible. Subsequently, the 3D virtual model was exported in Standard Triangle Language (STL) format to 3-Matic Medical software V.12 (Materialise, Leuven, Belgium). An observer indicated fiducial marks at the most lateral part of the condylar head and the angle of the mandible. Twenty 3D virtual models of mandibular stereolithography with fiducial marks and fuse deposition modeling (FDM) were manufactured using a Flashforge adventure-3 printer (Flashforge, ZheJiang, China).

A surgical simulation of segmental mandibulectomy was established on the 3D virtual mandibular model of the same patient. The planned segmental mandibulectomy model (planned SM model) was randomly cut at two different positions to create 20 mandibular defects (40 osteotomy planes) according to HCL classification[5]: two C defects, eight L defects, eight LC defects, and two LCL defects. This process was independently performed by one researcher. Using the STL file of these designs, the surgical cutting guides were printed with FDM using a Flashforge adventure-3 printer (Flashforge, ZheJiang, China).

Segmental mandibulectomy procedure

All segmental mandibulectomy procedures were performed on the mandibular stereolithography by one oral and maxillofacial surgeon. The surgical cutting guide was secured to the mandibular stereolithography using miniscrews, and the osteotomy was performed using a reciprocating saw (Sciencemedic Gyeonggi-do, South Korea). Following segmental mandibulectomy procedures, the remaining parts of the mandibular stereolithography were scanned using a CS 9600 CBCT scanner (Carestream Dental LLC, GA, USA) at 91 kVP, 2 mA, and 0.30-mm slice thicknesses. The obtained DICOM files were converted to a 3D virtual model (Post-SM model) in Mimics Research software V.20 (Materialise, Leuven, Belgium).

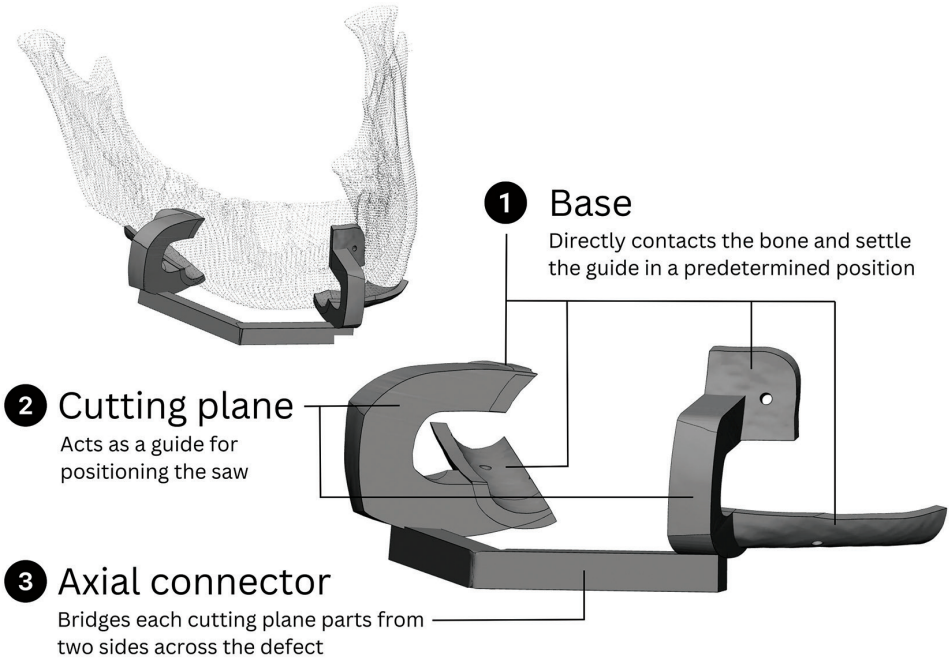

Figure 2: Diagram of virtual design of a three-dimensional model and an in-house personalized surgical cutting guide for mandibular reconstruction with nonvascularized iliac bone graft, with descriptions of each component.

Registration process and accuracy measurement of osteotomy

Using 3-Matic Medical software V.12 (Materialise, Leuven, Belgium), the post-SM model was superimposed onto the planned SM model and registered based on the remaining condyle-angle complex with fiducial marks. The osteotomy plane was created by defining three selected points on the cutting cross-sectional area, and the center points of each osteotomy plane were located. The osteotomy plane located distally to the defect was defined as the distal osteotomy plane, and those located medially to the defect were defined as the medial osteotomy plane. For type C defects, the osteotomy plane located on the left side of the defect referred to the medial osteotomy plane, and the contralateral side referred to the distal osteotomy plane. The angle formed by the osteotomy plane between the post-SM model and the planned SM model was the angulation deviation of osteotomy, and the distance deviation of the osteotomy plane was the distance between the center points.

The distortion of the surgical cutting guide and mandible model was also evaluated. All printed surgical cutting guides and mandible models were scanned using a cs 9600 CBCT scanner (Carestream Dental LLC, GA, USA) at 91 kVP, 2mA, and 0.30-mm slice thicknesses and converted to a 3D virtual model (actual guide model) in Mimics Research software V.20 (Materialise, Leuven, Belgium). The printed model was superimposed onto the virtual model using the Global Registration function, which allows to modify the distance threshold, the number of iterations and the subsample ratio to ensure maximum possible superimposition. After superimposition, a part comparison analysis was applied. The distortion of the surgical cutting guide and mandible models refers to the absolute distance deviation between the actual guide model and virtual guide model and the root mean square (RMS) value, automatically calculated within the software. All measurements were performed by one researcher. The accuracy measurement is presented in Figure 3.

Statistical analysis

The sample size and statistical analyses were calculated using Stata statistical software, release 17 (College Station, TX, USA: StataCorp LLC), based on a previous study[6], which reported that the mean deviation of the cutting plane was 0.2±0.3 degree with a considered 95% confidence interval (CI) and 80% test power. Consequently, the minimum sample size result was 20 cutting planes.

Before conducting the study, the reliability of the accuracy measurement was determined by ensuring that the intraclass correlation coefficient (ICC)[7] was equal to or greater than 0.75. All accuracy measurements were taken twice, one week apart, to maximize reliability. The average between the two values was chosen as a representative value. The absolute angulation and distance deviation of osteotomy were presented as mean, standard deviation (SD), and 95% CI. A boxplot was used to visualize the range of values covered by the data and any outliers.

Results

Regarding the distortion analysis, the absolute distance deviation of the surgical cutting guides was -0.3306±0.0565 mm, and the RMS was 0.8183±0.0255 mm for the entire guide surface. The absolute distance deviation of the mandible models was -0.2458±0.0522

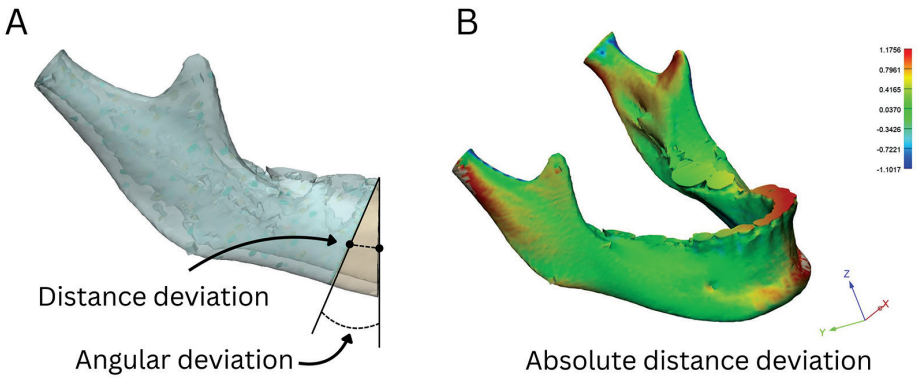

Figure 3: Error measurement between virtual and actual osteotomy in software using angular and distance deviation (A) and distortion analysis of model using absolute distance deviation (B).

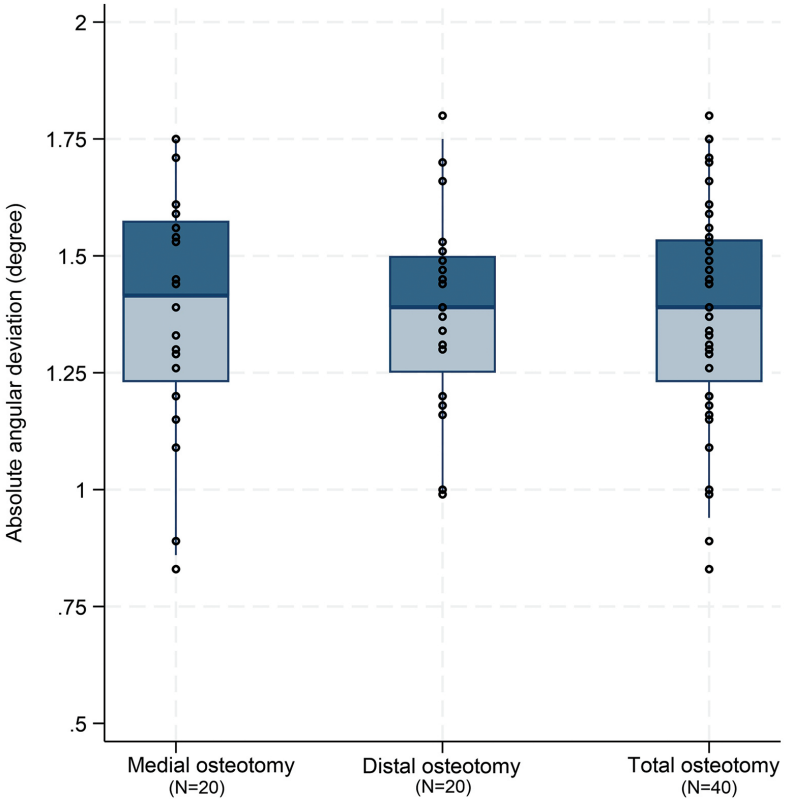

Figure 4: Angular deviation of osteotomy between virtual and actual osteotomy in model.

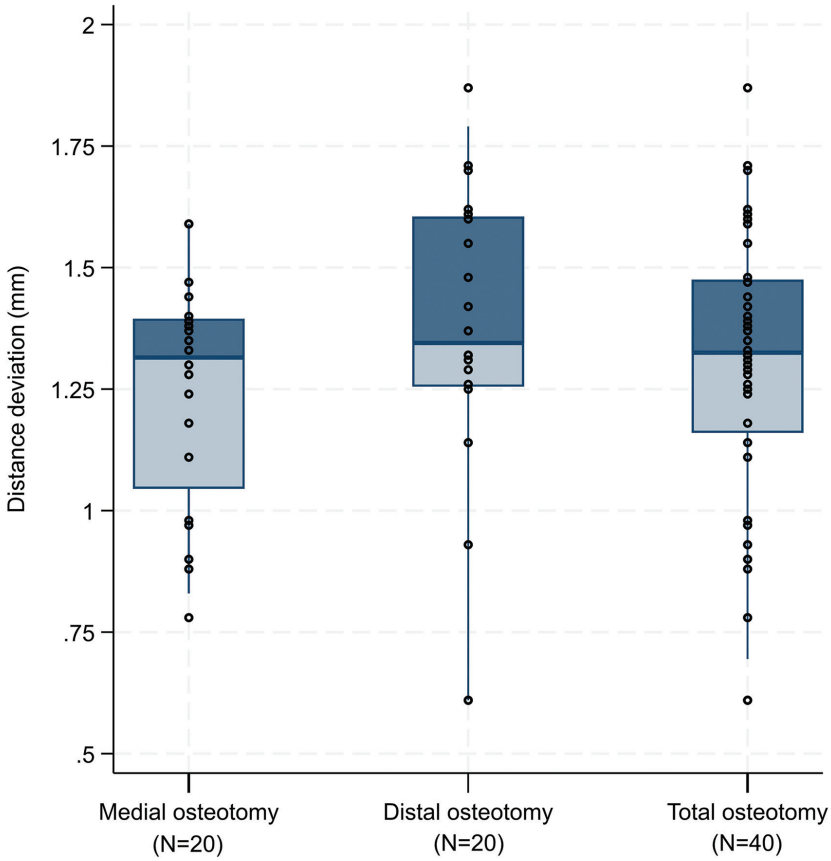

Figure 5: Distance deviation of osteotomy between virtual and actual osteotomy in model.

Table 1: Error in segmental mandibulectomy osteotomy.

No.	Type of defect*	Angular deviation (°)		Distance deviation (mm)	
		Medial osteotomy plane	Distal osteotomy plane	Medial osteotomy plane	Distal osteotomy plane
1	C	1.44	1.70	1.59	1.62
2	L	1.29	1.31	1.28	1.25
3	L	1.71	1.20	1.24	1.70
4	L	1.26	1.16	1.47	1.31
5	LC	1.39	0.99	0.88	1.42
6	L	1.33	1.30	1.39	1.60
7	LC	1.15	1.39	1.33	1.55
8	C	0.89	1.47	0.97	1.29
9	LC	1.75	1.53	0.98	0.61
10	LC	1.54	1.80	1.37	1.37
11	LC	1.59	1.49	1.35	1.87
12	LCL	1.56	1.51	1.18	1.48
13	LC	1.09	1.39	1.40	1.32
14	LCL	1.45	1.37	1.30	1.26
15	L	1.53	1.45	1.59	1.32
16	L	1.30	1.18	1.11	1.14
17	LC	1.61	1.34	1.44	1.61
18	L	1.75	1.44	1.38	0.61
19	L	0.83	1.00	0.78	0.93
20	LC	1.20	1.66	0.90	1.71
Average (mean ± SD)		1.38±0.26	1.36±0.22	1.27±0.23	1.35±0.33
Total (mean ± SD)		1.3835±0.2357 [95% CI; 1.3081-1.4588]		1.2975±0.2907 [95% CI; 1.2045-1.3904]	

Abbreviations: SD, standard deviation; mm, millimeters; CI, confident interval
*according to HCL classification by Boyd and colleagues (1993).

mm, and the RMS was 1.0453±0.0100 mm. The deviation of osteotomy using the in-house surgical cutting guide is shown in Table 1. The mean absolute angulation deviation of osteotomy (Figure 4) was 1.3835±0.2357 degree (95% CI: 1.3081-1.4588 degree), and the mean absolute distance deviation of osteotomy (Figure 5) was 1.2975±0.2907 mm (95% CI: 1.2045-1.3904 mm).

Discussion

Precise osteotomy is crucial for successful ablative surgery in patients with benign or malignant intraosseous tumors and for reducing local tumor recurrence. This ensures the complete removal of the tumor while preserving as much healthy tissue as possible, which is critical for maintaining the structural integrity and aesthetic appearance of the head and neck region. The application of CASs, such as virtual surgical planning, patient-specific cutting guides, and surgical navigation, has significantly enhanced the accuracy of osteotomy in surgery. Previous studies have shown that precise osteotomies with patient-specific cutting guides contributed to better surgical outcomes in terms of enhanced bony union, reduced operative time, and fewer complications when compared to the conventional freehand technique.[8-10]

When performing a segmental mandibulectomy using conventional techniques, maxillomandibular fixation was typically performed to maintain condylar position and occlusion after the continuity defect was created. Most novel CASs for the segmental mandibulectomy procedure typically help obtain precise surgical margins and eliminate the need for maxillomandibular fixation by using surgical cutting guides combined with customized titanium plates. However, using customized titanium plates incurs additional costs. Therefore, this CAS work-

flow has designed a surgical cutting guide that holds both segments together after osteotomy without the need for customized plates. The development of in-house surgical cutting guides for mandibular reconstruction offers several advantages, especially cost-effectiveness and faster production times. One challenge is proving the precision and validation of these in-house surgical cutting guides to ensure consistent and reliable outcomes.[11] Several studies have highlighted the role of CAS in mandibular reconstruction using vascularized bone grafts, especially vascularized fibula grafts or vascularized iliac bone grafts. Numajiri *et al*., developed low-cost surgical cutting guides for mandibular recon struction with free fibular flaps and found that the error of the osteotomy plan was 0.66 mm for mandibular osteotomies and 0.92 mm for fibular osteotomies.[12] Lim *et al*., also revealed that the average error of mandibular osteotomies was 1.1±0.6 mm when using printed cutting guides.[13] Recently, the navigated cutting guide system has been introduced, with the benefit of flexibility during surgery. Ter Braak *et al*.,[14] evaluated the accuracy of this navigated cutting guide and found that the error in distance was 1.1±0.6 mm, the error in yaw was 1.8±1.4 degree, and the error in roll was 1.6±1.3 degree.

This *in vitro* study validated the feasible performance of osteotomy using an in-house surgical cutting guide for partial mandibulectomy. This guide design had a mean angulation deviation (error) of 1.3835 degree and a mean distance deviation (error) of 1.2975 mm for osteotomy. The inaccuracies of CAS are caused by errors that occur during the processes of data acquisition, computer-assisted design, computer-assisted manufacturing, transfer to actual surgery, and postoperative evaluation. Van Baar *et al*., performed a systematic review and identified a variety of CAS planning approaches, ranging from data acquisition to postoperative evaluation. The ability to compare accuracy measurements in CAS was thus limited.[15] The clinically acceptable error for the osteotomy plane when using surgical cutting guides in mandibular reconstruction generally ranges from 1 to 3 mm, with 2 to 5 degree for angular deviations.[14,16] Thus, this proof-of-concept study showed that our in-house surgical cutting guide was not inferior to those reported in previous studies, achieving osteotomy planes with clinically acceptable values.

Some concerns remain that require clarification. First, as in previous studies using stereolithography models, the printed mandibular models could not be perfectly cut due to the plasticity of the material used. The error at the osteotomy plane might be greater than the error produced in clinical settings when the osteotomy is performed on real bone. Second, the approach to positioning the surgical cutting guide in a predetermined position and performing the osteotomy was straightforward, without any interference from other tissues as would occur in actual surgery. Future clinical studies are needed to confirm the precision. Third, the distortion of the printed mandibular models and surgical cutting guides also affects osteotomy deviations. The literature indicates that acceptable discrepancies between 3D printed medical models and reference data or RMS typically do not exceed 1 mm.[17] Thus, the distortion was acceptable in this present study; hence, it is unlikely to confound the error measurement. Fourth, the questionable rigidity of the surgical cutting guide could confound the accuracy of the second osteotomy. Since the surgical cutting guide's body must be sufficiently thin to provide visibility of the surgical field while maintaining adequate rigidity and stability, defining the optimal size of the surgical cutting guide that is clinically acceptable in this *in vitro* study is difficult. Lastly, when the mandibular model was cut manually, the errors of the surgical technique depended on the surgeon’s skill and perspective. To minimize this bias, all surgical procedures in this study were performed by a single expert surgeon.

Further improvements are planned to this in-house surgical cutting guide. Essentially, the surgical cutting guide should be rigid enough to stably bridge and secure the remaining parts of the mandible. The optimal size of the axial connector will be investigated and refined in future clinical studies to ensure rigidity. An effective surgical cutting guide should produce precise osteotomy regardless of the surgeon’s expertise. Future studies should evaluate the effectiveness across a diverse group of surgeons with varying levels of experience. Additionally, the accuracy, clinical feasibility, relevant clinical outcomes, and cost-effectiveness will be investigated in clinical settings. Such research will provide valuable insights into the applicability of this in-house surgical cutting guide and assist in refining its design and implementation. Thus, it will aid in developing more reliable surgical cutting guides for segmental mandibulectomy and iliac bone harvesting, ensuring precise surgical margins and accurate acquisition of bone volume for grafting the defect.

Conclusions

This *in vitro* study validated the feasibility of a surgical cutting guide design. This in-house personalized surgical cutting guide for segmental mandibulectomy,which is the component of in-house CAS workflow, facilitated the precise and reproducible osteotomy on the mandible before mandibular reconstruction, with clinically acceptable values. Further investigations in actual surgery are necessary to ensure clinical benefits.

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Conflicts of Interest

The authors declare that they hold no competing interests.

References

1. Bagheri SC, Bell RB, Khan HA. Current therapy in oral and maxillofacial surgery. Philadelphia: Elsevier Saunders; 2012.
2. Kumar BP, Venkatesh V, Kumar KA, Yadav BY, Mohan SR. Mandibular reconstruction: overview. J Maxillofac Oral Surg. 2016;15(4):425-41.
3. Powcharoen W, Yang WF, Yan Li K, Zhu W, Su YX. Computer-assisted versus conventional freehand mandibular reconstruction with fibula free flap: a systematic review and meta-analysis. Plast Reconstr Surg. 2019;144(6):1417-28.
4. Yang WF, Choi WS, Wong MC, Powcharoen W, Zhu WY, Tsoi JK, *et al*. Three-dimensionally printed patient-specific surgical plates increase accuracy of oncologic head and neck reconstruction versus conventional surgical plates: a comparative study. Ann Surg Oncol. 2021;28(1):363-75.
5. Boyd JB, Gullane PJ, Rotstein LE, Brown DH, Irish JC. Classification of mandibular defects. Plast Reconstr Surg. 1993;92(7):1266-75.
6. Donnez M, Ollivier M, Munier M, Berton P, Podgorski JP, Chabrand P, *et al*. Are three-dimensional patient-specific cutting guides for open wedge high tibial osteotomy accurate? an *in vitro* study. J Orthop Surg Res. 2018;13(1):171.
7. Koo TK, Li MY. A Guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med. 2016;15(2):155-63.
8. May MM, Howe BM, O'Byrne TJ, Alexander AE, Morris JM, Moore EJ, *et al*. Short and long-term outcomes of three-dimensional printed surgical guides and virtual surgical planning versus conventional methods for fibula free flap reconstruction of the mandible: decreased nonunion and complication rates. Head Neck. 2021;43(8):2342-52.
9. Bouchet B, Raoul G, Julieron B, Wojcik T. Functional and morphologic outcomes of CAD/CAM-assisted versus conventional microvascular fibular free flap reconstruction of the mandible: a retrospective study of 25 cases. J Stomatol Oral Maxillofac Surg. 2018;119(6):455-60.
10. Dalband M, Badkoobeh A, Alam M, Motie P, Tabrizi R. Comparison of the outcome of free iliac bone graft and vascularized iliac bone graft in reconstruction of mandibular defects: a systematic review. J Maxillofac Oral Surg. 2024; 23(6):1371-8.
11. Sun Q, Zhu Z, Meng F, Zhao R, Li X, Long X, *et al*. Application of a modified osteotomy and positioning integrative template system (MOPITS) based on a truncatable reconstruction model in the precise mandibular reconstruction with fibula free flap: a pilot clinical study. BMC Oral Health. 2023;23(1):842.
12. Numajiri T, Nakamura H, Sowa Y, Nishino K. Low-cost design and manufacturing of surgical guides for mandibular reconstruction using a fibula. Plast Reconstr Surg Glob Open. 2016;4(7):e805.
13. Lim SH, Kim MK, Kang SH. Precision of fibula positioning guide in mandibular reconstruction with a fibula graft. Head Face Med. 2016;12:7. doi: 10.1186/s13005-016-0104-2.
14. Ter Braak TP, Brouwer de Koning SG, van Alphen MJA, van der Heijden F, Schreuder WH, van Veen RLP, *et al*. A surgical navigated cutting guide for mandibular osteotomies: accuracy and reproducibility of an image-guided mandibular osteotomy. Int J Comput Ass Rad. 2020;15(10):1719-25.
15. Van Baar GJC, Forouzanfar T, Liberton N, Winters HAH, Leusink FKJ. Accuracy of computer-assisted surgery in mandibular reconstruction: a systematic review. Oral Oncol. 2018;84:52-60.
16. Bernstein JM, Daly MJ, Chan H, Qiu J, Goldstein D, Muhanna N, *et al*. Accuracy and reproducibility of virtual cutting guides and 3D-navigation for osteotomies of the mandible and maxilla. PLoS One. 2017;12(3):e0173111.
17. George E, Liacouras P, Rybicki FJ, Mitsouras D. Measuring and establishing the accuracy and reproducibility of 3D printed medical models. Radiographics. 2017;37:1424-50.

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Age-related Survival of Fixed Dental Prostheses: 7 to 12 Years Retrospective Study

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Abstract

Objectives: To compare the survival rate of teeth restored with fixed dental prostheses (FDPs) between elderly and non-elderly patients. Additionally, to study the characteristics and frequency of FDP failure in both groups.

Methods: FDP data were collected from patient records treated between 2009-2013. Oral examinations and radiographs were performed, recording success and failure characteristics of the FDPs. The survival rate of FDPs in the elderly compared to the younger group was analyzed using Pearson Chi-square and Fisher's Exact Test at a 95% confidence level.

Results: Out of 155 FDPs, 136 (87.7%) survived, while 19 (12.3%) failed, with an average age of 9.1 years. In the under-60 age group, 107 of 121 FDPs (88%) survived, and 14 (12%) failed. In the elderly group, 29 of 34 FDPs (85%) survived, while 5 (15%) failed. For post-and-core with crown restorations, 20 of 23 abutments (87%) survived, and 3 (13%) failed due to root lesions and fractures.

Conclusions: The overall 7- to 12-year survival rate of FDPs was 87.7%, with no statistically significant differences between elderly (85%) and younger (88%) patients at the 95% confidence level. The incidence of caries, periodontal conditions, root lesions, and the type of restorative material also showed no significant differences between the groups.

Keywords: elderly patients, fixed dental prosthesis, survival rate

Introduction

A fixed dental prosthesis (FDP) is a type of prosthesis that is permanently attached to one or more teeth, which may be either natural teeth or dental implants, and cannot be removed by the patient.[1] FDPs include various forms such as crowns, fixed partial dentures, and post and core with crowns.

Several factors must be considered when restoring a tooth with a FDP. These include the patient's systemic disease, the extent of damage and tooth structure loss in the abutment, the abutment's position, the characteristics of neighboring teeth, the occlusal scheme, and chewing force. Treatment planning and FDP design are further influenced by patient-specific factors such as expectations, economic status, and educational background. Understanding the success and survival rates of FDPs is essential for developing effective treatment plans tailored to individual patients.

The definition of survival was FPD staying *in situ*, whether or not it was altered. The FPDs' continued *in situ* status without any issues during the whole observation period was considered success.[1] For instance, resin composites can be used to repair fractured areas, such as chipped or cracked porcelain on the substructure, particularly when the affected area is not exposed to chewing forces. Therefore, the FDP is considered to have met the criteria for survival.

Studies on the survival rate of FDPs have varied in terms of factors and limitations. Bühler *et al*.,[2] investigated the survival rate of partial ceramic crowns treated by dental students and found an 86% survival rate at 5 years post-treatment. Güncü *et al*.,[3] reported a 98.1% survival rate for zirconia-based crowns over a 5-year period. Borén *et al*.,[4] conducted a study 10 years after treatment on teeth that had undergone root canal therapy, revealing a survival rate of 81.5%, predominantly in younger patients whose teeth were restored with crowns after root canal treatment. Numerous other studies have reported varying follow-up periods, types of FDPs, survival rates, and failure characteristics.[5-11]

A systematic review by Pieger *et al*.,[12] examined the survival rate of crowns and fixed partial dentures made from lithium disilicate. The study found that after 2 years, the survival rate for crowns was 100%, while for fixed partial dentures, it was 83.3%. After 5 years, fixed partial dentures had a survival rate of 78.1%, and crowns had a rate of 97.8%. The 10-year survival rate of fixed partial dentures was 70.9%, and crowns had a survival rate of 96.7%.

The number of elderly people in the world is increasing rapidly, and advancements in medical technology have contributed to a rise in the general population's average age.[13] According to the United Nations, age groups are determined by chronological age; a "older person" is often defined as someone who is 60 or 65 years of age or older. In addition, the retirement age in Thailand is established at 60 by the government.[14] In dentistry, the rate of tooth loss among the elderly has decreased, and the use of FDPs in this population is becoming more common. This trend is driven by the desire for both comfort and aesthetics in a form that closely resembles natural teeth.[15] However, numerous studies have shown that dental caries, periodontitis, and pulp infections are more prevalent in the elderly compared to younger age groups. This is often attributed to systemic diseases that influence changes in oral conditions, as well as diminished cleaning skills, leading to poor oral hygiene.[16,17] Therefore, it is crucial to effectively treat or restore the teeth of elderly patients with FDPs to ensure that these restorations function well in their mouths for an extended period.

Only a few studies have shown that the survival rate of FDPs decreases in older patients.[4,5] Currently, there is insufficient strong evidence to suggest that elderly patients receiving FDPs face an increased risk of failure.[18] There is no definitive correlation between FDP failure characteristics and advanced age. Therefore, research on characteristics, causes, and risks of these failures is essential. This includes promoting oral health, implementing preventive measures, ensuring follow-up care, and maintaining the condition of FDPs in elderly patients. Such knowledge can significantly influence clinical decisions related to diagnosis, prognosis, and treatment planning for older individuals requiring FDPs.

The purpose of this study was to compare the 7- to 12-year survival rates of FDPs in elderly patients with those in younger age groups. Additionally, it aimed to examine the characteristics and frequency of failures to inform treatment planning for FDPs in elderly patients.

Materials and Methods

This study received ethical approval under No. 26/2020 and 27/2020 from the Human Experimentation

Committee, Faculty of Dentistry, Chiang Mai University, Thailand. Data were collected from the dental treatment records of patients who received FDPs, including crowns, posts and cores with crowns, and bridges, at the Restorative Dentistry Clinic, Faculty of Dentistry, Chiang Mai University, between 2009 and 2013. The recorded information includes the following details:

1. Patient's general information, including name, hospital number (HN), age, gender, systemic disease, and chief complaint.

2. Dental information prior to FDP treatment:

2.1 Type of occlusion: canine guidance, group function, balance occlusion, and/or occlusal interference.

2.2 Location of abutments and/or edentulous area.

2.3 Clinical findings of abutments, including the presence of carious lesions, erosion, abrasion, attrition, tooth mobility, the presence of previous restorations, and/or root canal treatment, etc.

3. Information on FDPs and radiographic findings in a cementation visit, including:

3.1 Types of retainers: full crowns, three quarter crowns, reverse three quarter crowns, and seven-eight crowns.

3.2 Materials used for restoration: full metal, all-ceramic, and porcelain fused to metal (PFM).

3.3 Types of pontics: ovade, ridge lap, modified ridge lap, conical, and sanitary.

3.4 Types of posts and cores: custom cast metal post and core, fiber-reinforced composite post and core, amalgam post and core, previous post and core, and core without post.

3.5 Type of cement for post and core cementation: polycarboxylate, zinc phosphate, and resin cement.

3.6 Type of cement for retainer cementation: polycarboxylate, zinc phosphate cement, resin cement.

3.7 Crown-to-root ratio

3.8 Cementation date of the FDPs

The inclusion criteria for research participants are: individuals who received treatment with FDPs at the Restorative Dentistry Clinic, Faculty of Dentistry, Chiang Mai University, between 2009–2013, and who consented to participate in the research. The exclusion criteria are: individuals who could not be contacted by phone or postcard, and those who did not consent to participate in the research.

The oral examinations were performed by four examiners who had undergone calibration through interpersonal testing before starting the actual assessments. For cases where characteristics were challenging to assess, a supervising examiner provided the final decision. The data were maintained consistently with the information previously obtained from the treatment records, while also recording clinical findings related to failures in teeth restored with FDPs. These findings included the number and causes of previously restored teeth loss, dislodgement of FDPs, the occurrence of secondary caries around the margins, re-infection in previously root canal-treated teeth, chipped porcelain, tooth mobility, changes in periodontal pockets, etc. Additionally, periapical and bitewing radiographs were taken to document changes for comparison with the radiographs obtained from the original treatment records.

All information was collected, and patients were classified into two groups based on their age at the time of treatment: those aged 60 years and over, and those under 60. Survival rates were analyzed using the Pearson Chi-square statistic and Fisher's exact test at a 95% confidence level.

Results

Data collected from the oral examinations of the research participants revealed a total of 155 fixed dental prostheses (FDPs), including crowns, bridges, posts, and cores with crowns. When divided into two age groups, the group younger than 60 years had 121 FDPs, while the group aged 60 years and over had 34 FDPs. Of these, 136 FDPs survived, accounting for 87.7%, while 19 FDPs failed, representing 12.3%. The average functional lifespan of the prostheses was 9.1 years. When divided into two age groups, 121 FDPs (78%) were in the group under 60 years old, and 34 FDPs (22%) were in the group aged 60 years or older.

In the group of patients under 60 years of age, ranging from 20 to 59 years, the average age was 47 years. A total of 121 FDPs were placed, with a survival rate of 88% and a failure rate of 12%. Upon examination of the abutment teeth and the FDPs in the patients' oral cavities, 89 prostheses (74%) were found to be in good condition, while 32 prostheses (26%) showed some defects. These defects were categorized as follows: 3% were treatable periodontal diseases, 2% were periodontal diseases that did not improve after treatment, 1st degree mobility was found

in 5 teeth (4%), and 2nd degree mobility in 3 teeth (3%). Additionally, 5 teeth (4%) had periapical lesions, and 6 teeth (5%) exhibited carious lesions. Among the prostheses, 5% were in poor condition but repairable, 2% required replacement with new prostheses, and 6% had been extracted. The survival rates for different types of restorations were as follows: 93% for all-metal prostheses, 100% for partial crowns, 93% for metal-ceramic prostheses, and 100% for all-ceramic crowns.

In the elderly group, aged between 60 and 81 years with an average age of 65, a total of 34 FDPs were placed, with a survival rate of 85% and a failure rate of 15%. Upon examination of the abutment teeth and FDPs in the patients' oral cavities, 23 prostheses (67%) were found to be in good condition, while 11 prostheses (33%) showed some defects. These defects included: 3% treatable periodontal diseases, 6% 1st degree tooth mobility (2 teeth), 3% periapical lesions (1 tooth), and 10% carious lesions (3 teeth). Additionally, 3% of the prostheses were in poor condition but repairable, 6% required replacement with new prostheses, and 6% had been extracted. The survival rates for different types of restorations were as follows: 94.7% for all-metal prostheses and 86.7% for metal-ceramic prostheses.

When comparing the two groups, it was found that the survival rate of FDPs was 88% in the group under 60 years of age and 85% in the elderly group. The difference in survival rates between these two groups was not statistically significant, as shown in Figure 1.

The incidence of caries in abutment teeth was 5% in the group under 60 years of age and 10% in the elderly group. The difference in caries incidence between these two groups was not statistically significant, as shown in Figure 2.

The incidence of tooth mobility in abutment teeth was as follows: in the group under 60 years of age, 4% of teeth exhibited 1st degree mobility and 3% exhibited 2nd degree mobility. In the elderly group, 6% of teeth exhibited 1st degree mobility. The differences in tooth mobility between these two groups were not statistically significant, as shown in Figure 3.

The incidence of periapical lesions in abutment teeth was 4% in the group under 60 years of age and 3% in the elderly group. The difference in the incidence of periapical lesions between these two groups was not statistically significant, as shown in Figure 4.

The types of prostheses and their survival rates in both age groups revealed that all-ceramic crowns and

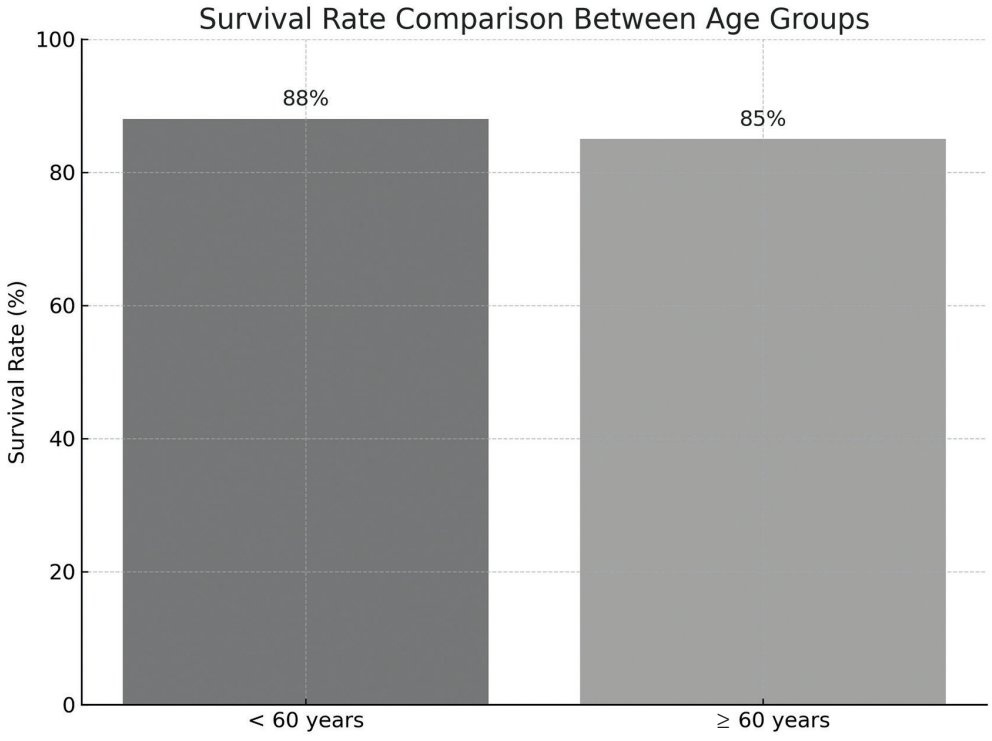

Figure 1: A chart showing a comparison of survival rates between two age groups: under than 60 years and elderly groups.

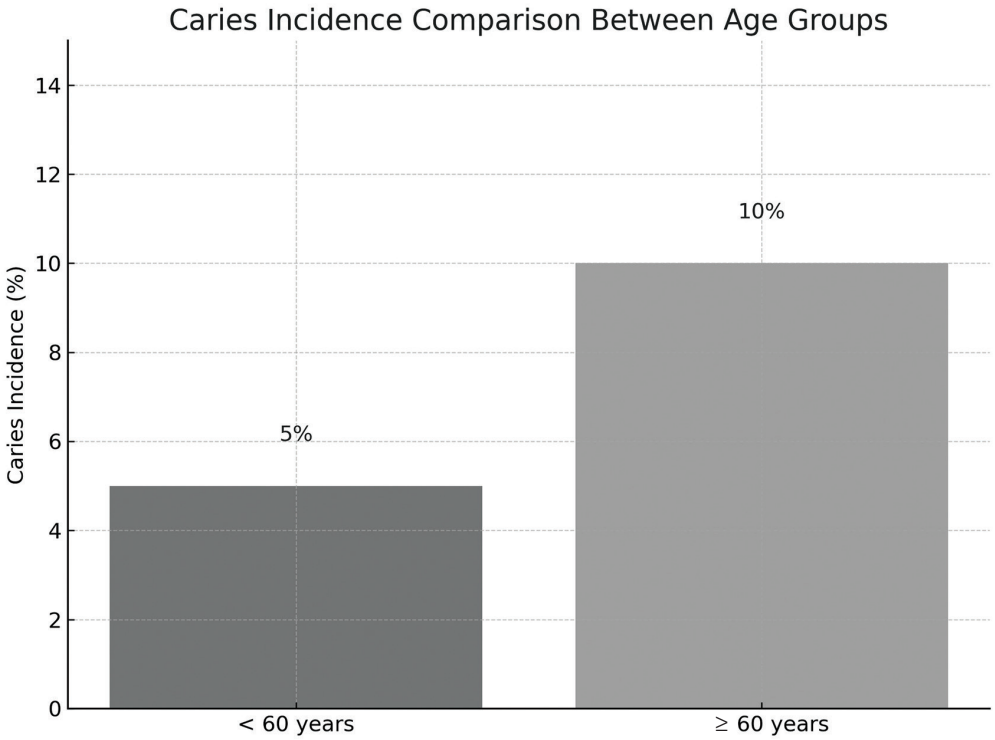

Figure 2: A chart showing a comparison of caries incidence between two age groups: under than 60 years and elderly groups.

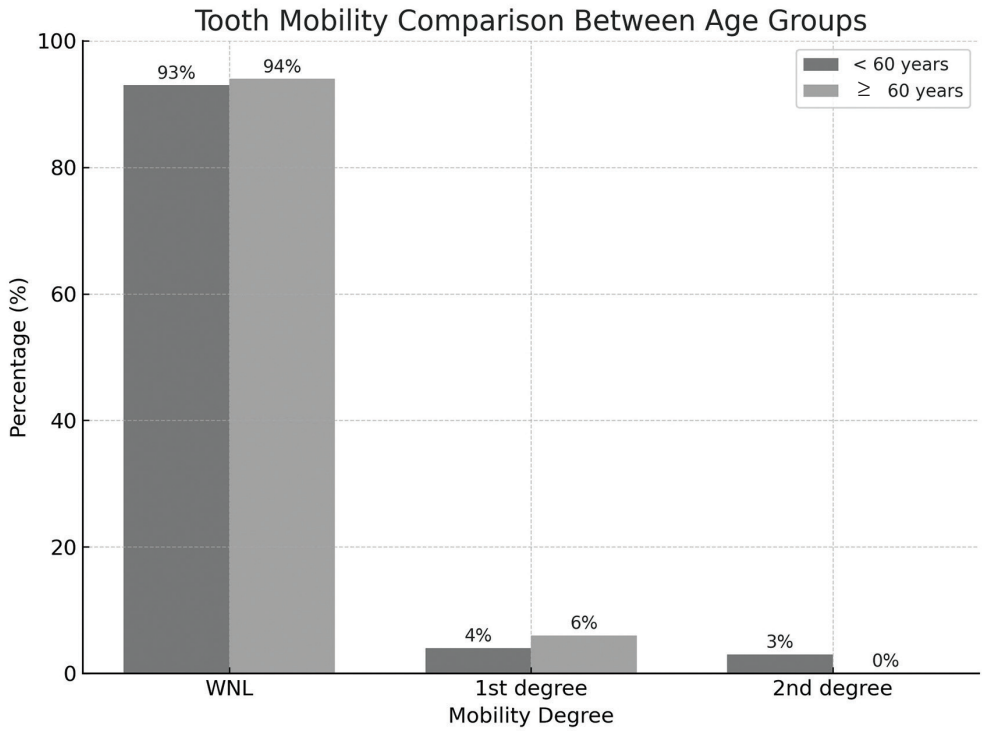

Figure 3: A chart showing a comparison of tooth mobility incidence between two age groups: under than 60 years and elderly groups.

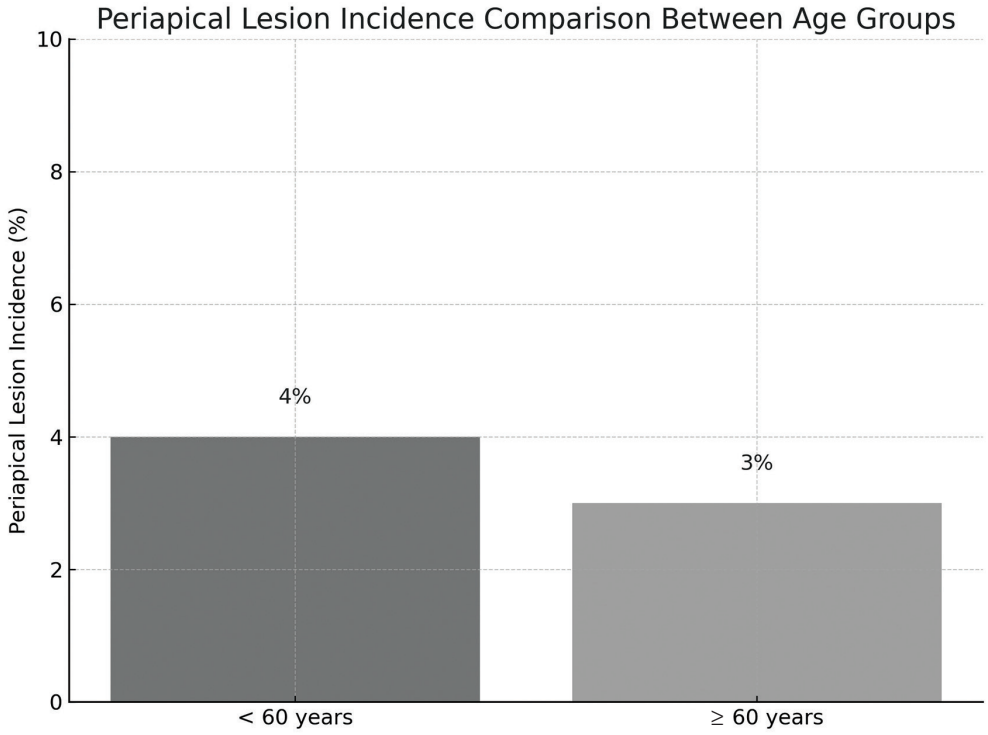

Figure 4: A chart showing a comparison of periapical lesion incidence between two age groups: under than 60 years and elderly groups.

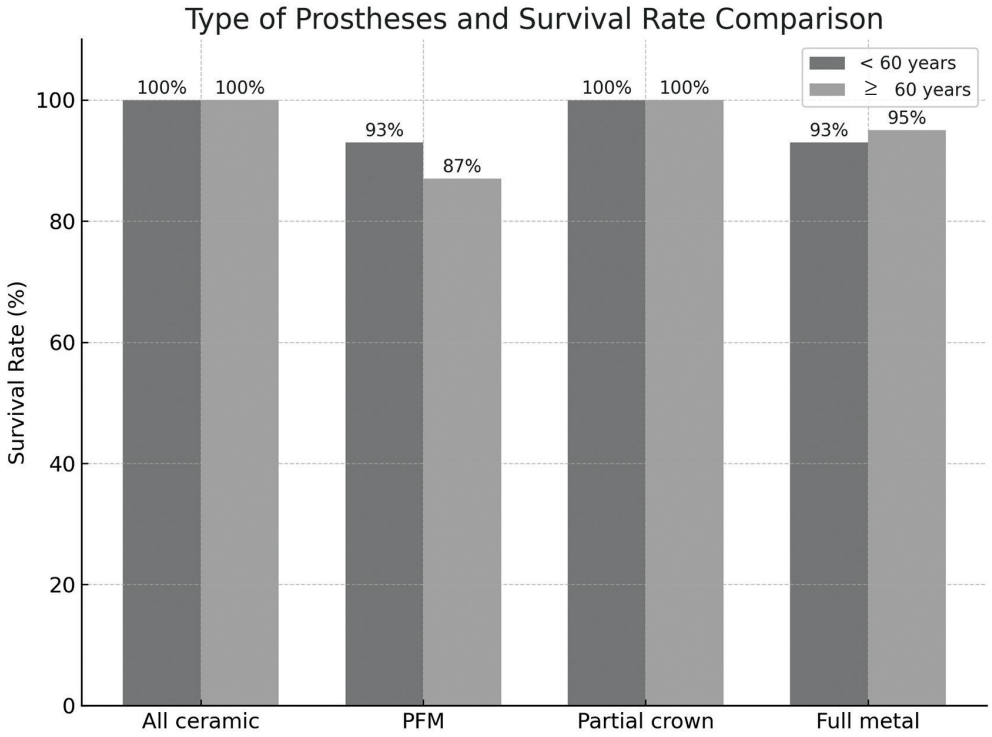

Figure 5: A chart showing a comparison of the survival rates of different types of fixed dental prosthetic materials between two age groups: under than 60 years and elderly group.

partial crowns in the group under 60 years of age had a 100% survival rate. The survival rates of metal-ceramic and all-metal prostheses did not differ significantly between the two age groups, as shown in Figure 5.

In this study, a total of 23 teeth were restored with post-and-core systems, with 78.26% in the group under 60 years old and 21.74% in the elderly group. Among these, 78.3% were metal posts, 17.4% were fiber posts, and 3.33% were amalgam posts. The survival rate for post-and-core restorations was 100% in the elderly group and 83.33% in the group under 60, with no statistically significant difference. Failures were observed in the form of periapical lesions in 2 teeth restored with metal posts and root fractures in 1 tooth restored with a fiber post.

When examining the condition of abutment teeth and restorations involving post-and-core systems with crowns, several deformities were identified: 4% of the teeth had been extracted, 9% presented with periapical lesions, 13% showed carious lesions, 13% of the restorations exhibited porcelain chipping or wear that could be repaired, and 4% had periodontal disease.

Discussion

This study found that age did not affect the survival of FDPs. Both the group under 60 years of age and the elderly group showed no statistically significant differences in survival rates (Figure 1). These findings are in agreement with the study by Loannidis *et al*.,[18] a systematic review examining the influence of patient age on the longevity of teeth supporting FDPs. Most studies in this systematic review reported that patient age had no statistically significant impact on the survival of FDPs, concluding that increased patient age should not be considered a risk factor for the survival of the FDPs. However, studies by Malament *et al*.,[19] and Palmqvist *et al*.,[20] reported higher failure rates in middle-aged patients compared to younger patients. Additionally, the study by De Backer *et al*.,[21] indicated a worse prognosis for elderly patients.

Due to the differences in the number of FDPs between the elderly group and those under 60 years of age in this study, this may have influenced the interpretation of the differences in survival rates. Additionally, a limitation of this study is the inability to specify the exact time frame for the occurrence of FDPs failure. Additionally, in this study, patients were grouped by age based on the date the FDPs were placed. Thus, even if FDP failure occurred when the patient was over 60 years old, they would still be classified in the younger age group, as the FDPs were placed when they were under 60.

Moreover, during the study, the COVID-19 pandemic occurred, which may have affected the results. Some patients may have FDPs failure, such as tooth extraction, or elderly patients may have declined to attend follow-up oral examinations, making them unable to participate in the study. This could be one of the errors the actual survival rates of the FDPs. Additionally, the variation in the number of different types of FDPs between the two age groups (Figure 5), such as the presence of partial crowns and all-ceramic crowns in the group under 60 years of age, while these FDPs were either few or absent in the elderly group, represents another limitation in interpreting the results of this study.

In the evaluation of post-and-core restorations, it was found that there was a difference in the number of patients between the two study groups. The elderly group had fewer patients, which may be one reason why failures were observed only in the group under 60 years of age. Moreover, most defects were found to be related to the crowns. The observed failures included the occurrence of periapical lesions and teeth that had been extracted due to root fractures.

The findings of this study, which showed no difference in the failure rates of FDPs between the elderly group and those under 60, may be attributed to the thorough assessment and treatment planning performed by dental students under close supervision and guidance from instructors. This approach contributes to better functionality and higher survival rates of restorations. If proper postoperative care is provided, including oral health promotion and preventive measures tailored for patients, along with regular follow-up visits to monitor the restorations and abutment teeth, the success rate can be further increased.

Conclusions

The study of all FDPs showed an overall 7- to 12-year survival rate of 87.7%, with 85% in the elderly group and 88% in the younger group. When comparing the two groups in terms of survival rates, caries incidence, periodontal conditions, periapical lesions, and types of restorative materials with prosthetic survival, no statistically significant differences were found at the 95% confidence level.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Pjetursson BE, Tan K, Lang NP, Brägger U, Egger M, Zwahlen M. A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after an observation period of at least 5 years. Clin Oral Implants Res. 2004;15(6):625-42.
2. Bühler J, Naef MA, Amato M, Krastl G, Weiger R, Zitzmann NU. Partial ceramic crowns prepared by dental students: clinical performance up to five years. J Dent Educ. 2017;81(6):732-43.
3. Güncü MB, Cakan U, Muhtarogullari M, Canay S. Zirconia-based crowns up to 5 years in function: a retrospective clinical study and evaluation of prosthetic restorations and failures. Int J Prosthodont. 2015;28(2):152-7.
4. Borén DL, Jonasson P, Kvist T. Long-term survival of endodontically treated teeth at a public dental specialist clinic. J Endod. 2015;41(2):176-81.
5. Behr M, Zeman F, Baitinger T, Galler J, Koller M, Handel G, *et al*. The clinical performance of porcelain-fused-to-metal precious alloy single crowns: chipping, recurrent caries, periodontitis, and loss of retention. Int J Prosthodont. 2014;27(2):153-60.
6. Svanborg P, Längström L, Lundh RM, Bjerkstig G, Ortorp A. A 5-year retrospective study of cobalt-chromium-based fixed dental prostheses. Int J Prosthodont. 2013;26(4):343-9.
7. Pjetursson BE, Bragger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). Clin Oral Implants Res. 2007;18 (Suppl 3):97-113.
8. Chifor I, Mitrea A, Badea I, Chifor R, Badea M, Mitrea P, *et al*. Mathematical methods for assessing the prognostic of fixed partial dentures resulting from evaluating a group of dental patients in Romania. Comput Math Methods Med. 2014;2014:984901.
9. Rosenstiel SF, Land MF, Walter R. Contemporary Fixed Prosthodontics: Elsevier Health Sciences; 2022.
10. Martino N, Truong C, Clark AE, O'Neill E, Hsu S-M, Neal D, *et al*. Retrospective analysis of survival rates of post-and-cores in a dental school setting. J Prosthet Dent. 2020;123(3):434-41.
11. Juloski J, Fadda GM, Monticelli F, Fajó-Pascual M, Goracci C, Ferrari M. Four-year survival of endodontically treated premolars restored with fiber posts. J Dent Res. 2014;93 (7 suppl):52S-8S.
12. Pieger S, Salman A, Bidra AS. Clinical outcomes of lithium disilicate single crowns and partial fixed dental prostheses: a systematic review. J Prosthet Dent. 2014;112(1):22-30.
13. MacEntee MI, Nolan A, Thomason JM. Oral mucosal and osseous disorders in frail elders. Gerodontology. 2004;21(2):78-84.
14. United Nations, Department of Economic and Social Affairs, Population Division. World Population Ageing 2019 [Internet]. New York: United Nations; 2020 [cited 2023 Nov 1]. Available from: https://www.un.org/development/desa/pd/content/world-population-ageing-2019
15. Shetty VD, Bijle MNA, Patil S. The relationship between prosthetic status and the Geriatric Oral Health Assessment Index in a group of institutionalized elderly of an Indian city: a cross-sectional study. J Contemp Dent Pract. 2013;14(6):1173-7.
16. Thomson WM. Epidemiology of oral health conditions in older people. Gerodontology. 2014;31(Suppl 1):9-16.
17. Hahnel S, Schwarz S, Zeman F, Schäfer L, Behr M. Prevalence of xerostomia and hyposalivation and their association with quality of life in elderly patients in dependence on dental status and prosthetic rehabilitation: a pilot study. J Dent. 2014;42(6):664-70.
18. Ioannidis G, Paschalidis T, Petridis HP, Anastassiadou V. The influence of age on tooth supported fixed prosthetic restoration longevity. a systematic review. J Dent. 2010;38(3):173-81.
19. Malament KA, Socransky SS. Survival of Dicor glass-ceramic dental restorations over 14 years: Part I. Survival of Dicor complete coverage restorations and effect of internal surface acid etching, tooth position, gender, and age. J Prosthet Dent. 1999;81(1):23-32.
20. Palmqvist S, Söderfeldt B. Multivariate analyses of factors influencing the longevity of fixed partial dentures, retainers, and abutments. J Prosthet Dent. 1994;71(3):245-50.
21. Backer HD, Maele GV, Moor ND, Berghe LV. The influence of gender and age on fixed prosthetic restoration longevity: an up to 18-to 20-year follow-up in an undergraduate clinic. Inter J Prosthodont. 2007;20(6):579-86.

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