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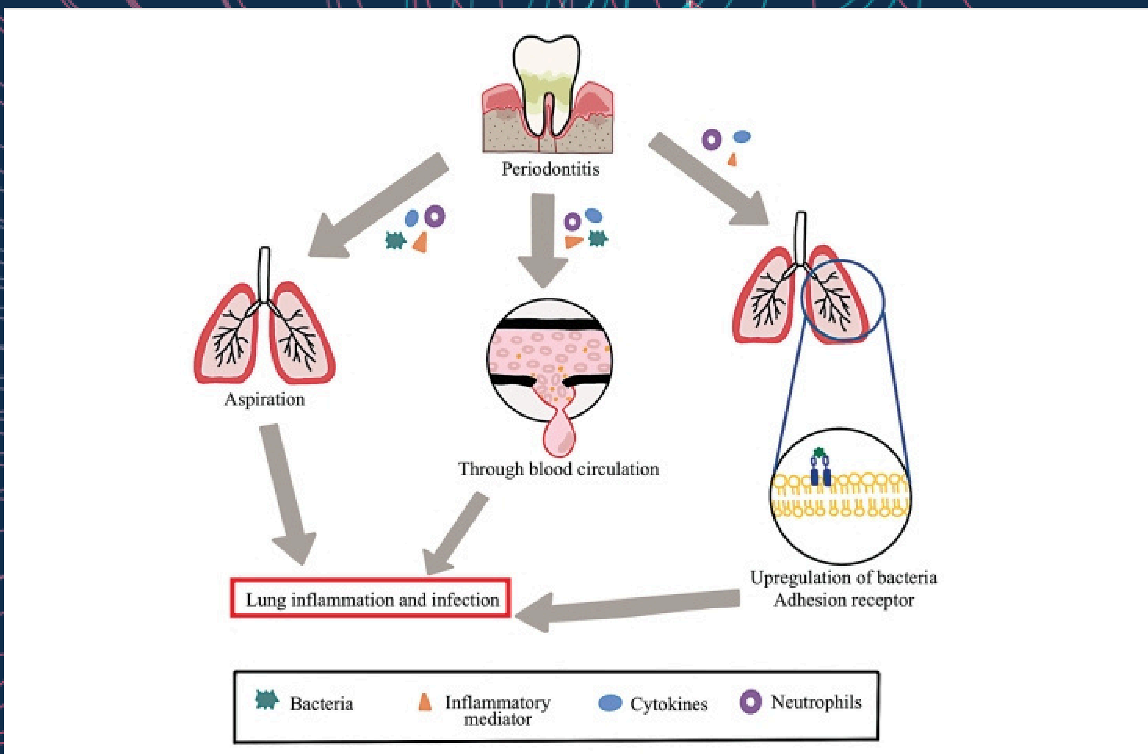

Chiang Mai University's Faculty of Dentistry publishes academic research articles in the newly titled - **Oral Sciences Reports,** which was previously known as *Chiang Mai Dental Journal (CMDJ)*. The journal was originally established for the purposes of publishing academic research articles by the 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.

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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).
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Editorial Board

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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 Original Articles — Original contributions of research reports or unpublished recent academic research to the development and applications in dentistry and related fields.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.
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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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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.

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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.

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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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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.

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• *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.

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• *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.

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• 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™ 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.

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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.

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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:

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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.

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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.

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Dental Implant Artifacts in MRI: Compatibility and Considerations

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Abstract

This review investigated dental implant artifacts in magnetic resonance imaging (MRI) and their safety in clinical practice. Dental prostheses, including implants, crowns, and orthodontic appliances, cause artifacts due to their high magnetic susceptibility, particularly in materials like iron, stainless steel, and cobalt-chromium. Titanium implants are considered safe under MRI environments according to the American Society for Testing and Material (ASTM) standards, with no reported thermal injury or dislodgement during examinations. Despite limited artifacts from titanium's paramagnetic nature, minute ferromagnetic components can still affect visualization. Thus, reducing artifacts in oral and maxillofacial MRI scans is crucial.

Two main categories of artifact reduction techniques are identified: improved porous titanium or alternative materials like zirconia and adjusting MR parameters with advanced sequences. Recommendations include increasing the readout bandwidth, reducing slice thickness, using spin-echo sequences instead of gradient-echo, and employing short tau inversion recovery or DIXON techniques for fat suppression. Additional methods like VAT, VAT-SEMAC combination, and MAVRIC show promise, although applicability may be restricted in specific MRI scanners.

Continuous advancements in dental implant materials and MRI sequences are needed to improve imaging quality and reduce artifacts. Collaboration among dental practitioners, radiologists, and MRI technologists is essential for refining techniques and ensuring patient safety. Although overall dental implant artifacts pose challenges, safety in MRI is well-established. Ongoing developments hold significant potential to enhance MRI imaging quality in patients with dental devices.

Keywords: artifact reduction techniques, dental implant artifact, MRI compatibility, MRI safety, titanium implants

Introduction

Dental implants have become a popular and widely used treatment option for patients with missing teeth. While there are less invasive alternatives that involve preserving natural teeth, dental implants offer a viable solution if these options are not feasible or fail to provide satisfactory results.[1] The prevalence of dental implants has seen a significant rise in recent years, with studies indicating an increase from 0.7% in 1999-2000 to 5.7% in 2015-2016 among adults missing any teeth in the United States. This growth is especially prominent in the 55 to 64 age group, with projections suggesting continued expansion but limited overall access by 2026.[2]

Magnetic Resonance Imaging (MRI) is a non-invasive imaging technique widely used for evaluating various medical and dental conditions without involving ionizing radiation.[3,4] In dentistry, MRI finds major applications in examining soft tissue lesions, salivary gland pathologies, and internal derangements of the temporomandibular joint (TMJ), benefiting from its exceptional soft tissue contrast resolution. Researchers have noted MRI's superiority in detecting tumor staging, odontogenic cysts, and perineural spread compared to computed tomography (CT).[4,5] Moreover, MRI has emerged as a valuable tool for dental implant planning and postoperative evaluation due to its ability to define implant positions and assess relations with the inferior alveolar nerve.[3,6-9] In certain cases, MRI can even be a viable alternative to CBCT for fully guided implant placement,[10] making it potentially useful throughout the workflow of implant surgery.[11]

Despite its benefits, MRI is contraindicated in patients with ferromagnetic medical devices or dental materials in their bodies, as these can interact detrimentally with the MRI's magnetic field. Such interactions may result in undesirable effects like artifact production, radiofrequency (RF)-induced heating, and magnetically induced displacement of objects. Among dental materials, metallic dental devices like orthodontic brackets, metal crowns, and dental implants have been found to cause artifacts in oral and maxillofacial MRI, potentially complicating diagnostic interpretations.[6,8,9,12] This review aims to elucidate the specific artifacts that can emerge in oral and maxillofacial MRI due to dental materials, with a particular focus on dental implants. Furthermore, the review will offer insights into MRI safety considerations for patients with implant-retained restorations undergoing MRI examinations.

MRI Physics and Artifact Formation

MRI physics

MRI is a diagnostic imaging technique that relies on the behavior of hydrogen atoms (H^+) in a strong magnetic field (B_0). Each H^+ spins randomly at a specific speed known as the 'Larmor frequency', which depends on the strength of the local static magnetic field B_0. This relationship is represented by the following equation[13]:

$$\omega = \gamma B_0,$$

where ω is the Larmor frequency in MHz, γ is the gyromagnetic ratio in MHz/Tesla, and B_0 is the strength of the static magnetic field in Tesla. Common human imging procedures use 1.5T or 3T magnetic field strengths. For instance, at 1.5T, the Larmor frequency of a hydrogen proton is approximately 63.8 MHz.

When patients or objects with hydrogen nuclei are placed in a strong magnetic field, the hydrogen nuclei align and undergo precession around the magnetic field in the similar manner that gyroscopes or tops precess around a gravitational field. Resonance is initiated by applying short-burst RF pulses with a frequency and speed similar to that of the H^+ spins. These RF pulses are emitted from the RF coils built into the MRI unit. The H^+ align themselves, spin synchronously (in-phase) and simultaneously flip according to the angle of the RF pulses (e.g., 90° or 180°). Different degrees of resonance can be achieved, emphasizing or de-emphasizing certain tissue types. After the RF pulses are switched off, the H^+ relax back to their original stage with T1 (longitudinal) and T2 (transverse) relaxation times. Simultaneously, the energy released from the atoms is detected by the receiver coil, inducing an electrical voltage that is processed to create MR images.[4,12,13] The diagram showing basic MR physics is illustrated in Figure 1.

Magnetic susceptibility

Magnetic susceptibility is the dimensionless ratio of the magnetization (M) in a material to the intensity of the magnetic field (H). It is measured in amperes per meter ($A \cdot m^{-1}$) and expressed in parts per million (ppm or 10^{-6}) as Chi (χ). The relationship of these parameters is defined by the following equation[14]:

$$\chi = \frac{M}{H}$$

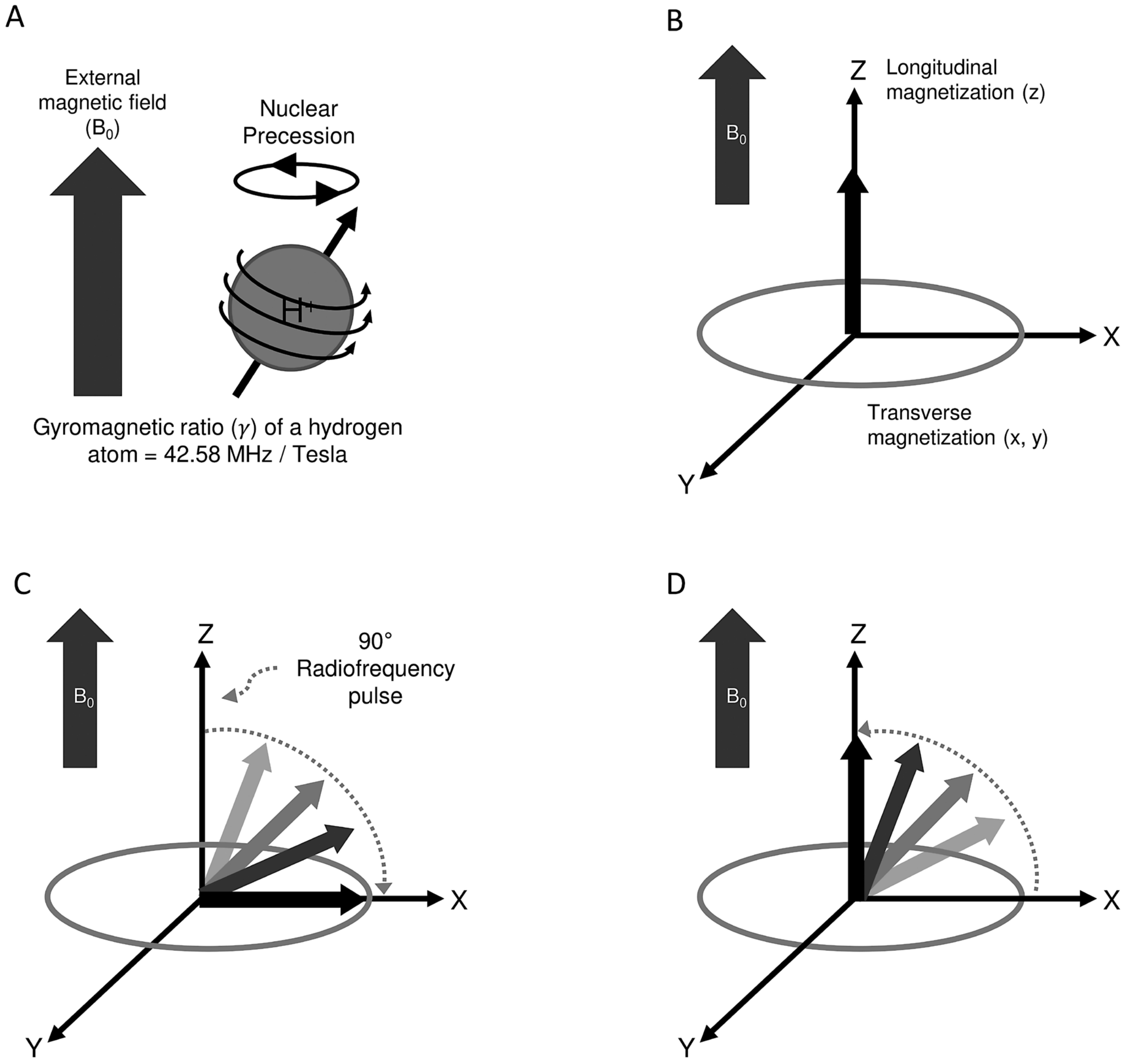

Figure 1: Diagram of basic MRI physics: A, Hydrogen atom or proton (H^+) precesses when placed in the external magnetic field (B_0) with its gyromagnetic ratio (γ) of 42.58 MHz/Tesla; B, when protons are positioned in the B_0, they align in longitudinal magnetization (z); C, when a 90° radiofrequency (RF) pulse is applied, protons move to transverse plane (x, y); D, when the RF pulse is switched off, protons relax back to their original state.

In other words, magnetic susceptibility determines the material's ability to be magnetized by an external magnetic field. Materials can be characterized into three types based on their magnetic susceptibility,[15-17] as illustrated in Figure 2 and described in Table 1[18-20]:

1. Diamagnetism (χ < 0 ppm): These materials have negative magnetic susceptibility and are repelled by magnets. They are less likely to cause MRI artifacts. Examples include wood, zinc, copper, silver, gold, and most biological tissues.

2. Paramagnetism (0<χ< 300 ppm): These materials have positive magnetic susceptibility and weakly attract to a magnet. They are far less likely to cause MRI artifacts. Examples include lithium, tantalum, titanium, and dental amalgam.

3. Ferromagnetism (χ>300 ppm): These materials have high magnetic susceptibility values and are strongly attracted to a magnet. They have a high potential to cause MRI artifacts when positioned in the patient's body due to the significant difference in magnetic susceptibility between these materials and human tissues. Examples include ferrite (iron), magnetite, and stainless steel.

Even materials with trace amounts of ferromagnetic ingredients can cause artifacts and disturbances in MRI. Dental restorations such as gold and titanium are less likely to induce artifacts, but they can generate artifacts and distortions due to traces of other ferromagnetic metal components, especially iron.[21] Understanding the magnetic susceptibility of dental implant materials is crucial in managing potential artifacts and ensuring patient safety during MRI procedures.

Dental implant materials and artifact formation

To replace missing teeth, oral implants are recommended as the treatment of choice.[22] These dental implants are typically made from various materials, each having its own advantages and disadvantages. One common material used for dental implants is titanium and its alloys because of its biocompatibility, corrosion resistance, high strength for resisting occlusal force and suitable modulus for transmitting force to bone.[23] The American Society for Testing and Materials (ASTM) classified titanium implants into six grades. Four of these grades (grades I to IV) are commercially pure titanium (CpTi), known as unalloyed titanium. The mechanical property of CpTi was improved by oxygen, nitrogen, carbon, and iron. It can result in increasing the concentration of these trace elements from grade I to IV, respectively.[23,24] Grade IV CpTi is the most used type of titanium for dental implants because it has the highest oxygen content (0.4%) and excellent mechanical strength.[25] The other two grades (Grades V and VI) are titanium alloys. Grade V titanium (Ti-6Al-4) is an alloy composed of 90% titanium, 6% aluminum (Al), and 4% vanadium (V). The alloying elements enhance the material's strength and stability. Grade VI, also known as Ti-6Al-4V ELI (Extra Low Interstitial), has a similar composition to Grade V but with lower levels of interstitial elements like oxygen and iron. This results in improved ductility and toughness. Titanium alloys have become prominent in biomedical applications due to their cost-effectiveness and desirable properties. These alloys are categorized based on their stabilizing elements: alpha (α), beta (β), or a combination (α-β). The most common dental alloy, Ti-6Al-4V, offers high strength and corrosion resistance. However, concerns about the potential toxicity of aluminum and vanadium have led to the development of alternative alloys using non-toxic elements like niobium, tantalum, zirconium, and palladium. The surface composition of titanium implants, typically TiO_2, plays a crucial role in bone interaction and corrosion resistance. Recent advancements include a binary titanium-zirconium alloy

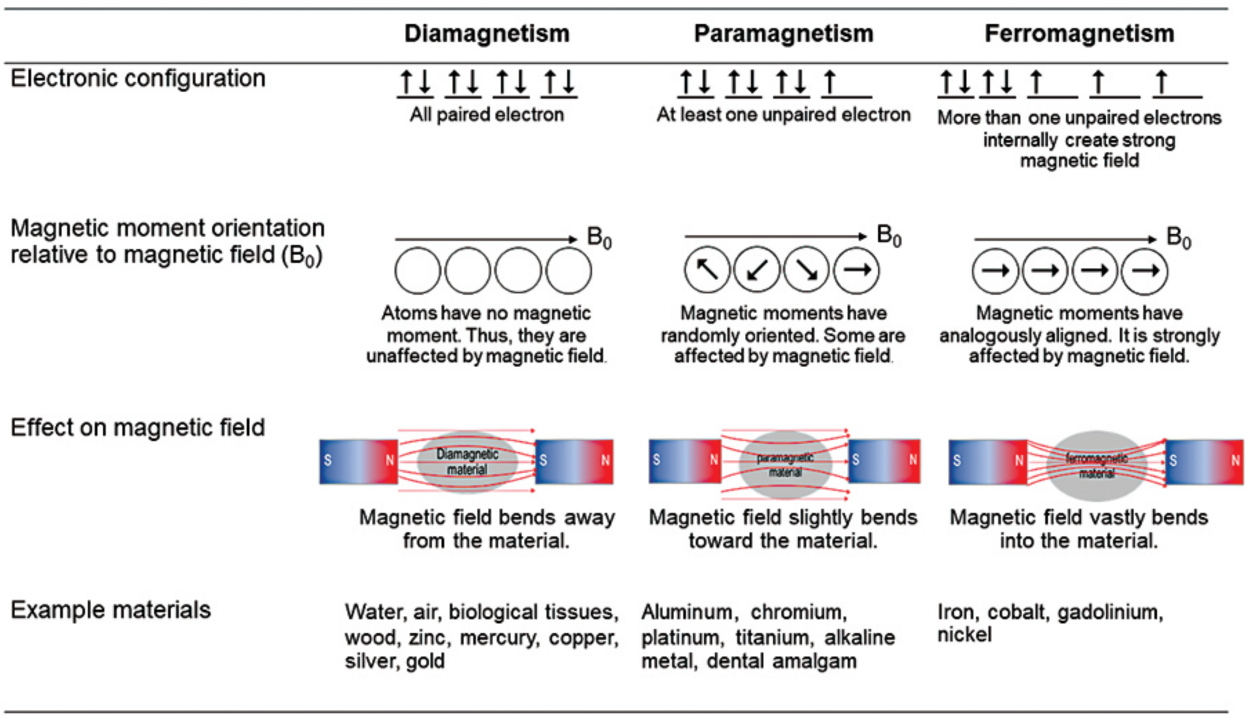

Figure 2: Illustration of each type of magnetism showing schematic diagrams of electronic configuration, magnetic moment orientations relative to magnetic field, schematic diagrams of effect on magnetic field, and examples of materials in response to such magnetism.

Table 1: Magnetic susceptibility (χ) of biological compounds and various prosthetic materials that could be found in human body.(17-19)

Materials	χ (ppm)
Gold	−34.0
Human bone	−11.0 to −8.86
Human tissue	−11.0 to −7.0
Copper	−9.63
Water (37°C)	−9.05
Air	0.264
Aluminum	20.7
Zirconium	109
Titanium	182
Gadolinium-based contrast agent (0.1 mol / l)	249
Platinum	279
Chromium-cobalt	900
Stainless steel	9000
Iron	200×10^9

(Roxolid®, Straumann Manufacturing Inc., Mansfield, TX, USA) that demonstrates improved strength and bone integration compared to traditional titanium alloys. These developments reflect ongoing efforts to enhance the biocompatibility and performance of dental implant materials.(26)

Recent research indicates that titanium implants produce more severe artifacts than zirconia implants, making zirconia a preferable option in scenarios where MRI compatibility is crucial. For instance, a study highlighted that titanium and titanium-zirconium alloys generated extensive artifacts compared to zirconium implants, which had minor distortion artifacts.(9) The metal-related MRI artifacts are described in the following section.

Types of MRI artifacts associated with metallic dental materials

The presence of metallic dental materials in the MRI field of view can lead to several types of artifacts that can affect image quality, as displayed in Figure 3. These artifacts depend on the shape and form of the implant material and can be classified as follows(27):

1. Signal void due to dephasing: rapid changes in magnetic field variations near metal objects cause magnetization within a single image to precess at different rates. This results in dephasing or loss of coherence, leading to signal void and the appearance of black areas in the MR image.

2. Failure of fat suppression: fat suppression techniques are commonly used in MR examinations to suppress signals from adipose tissue. However, the high signal from fat can still be recognized in the presence of metallic materials, reducing the effectiveness of fat suppression in the vicinity of dental materials.

3. Displacement artifacts: these artifacts result from geometric distortion, signal void, and signal pile-up during the process of slice selection and readout directions. The varying frequency induced by metallic materials can cause the MRI machine to select incorrect positions, leading to errors such as slice shifting, curving, and disunion of multiple regions known as pile-up effects.

During MRI, the magnetic field causes protons in the body's tissues to precess, generating signals used to create images. However, the magnetic susceptibility of titanium dental implants significantly differs from that of surrounding biological tissues, leading to increased frequency offsets and magnetic field inhomogeneity. Ferromagnetic metals present in dental materials can create their own magnetic fields, inducing a precession of proton frequencies in neighboring body tissues. This disruption of normal precession results in susceptibility artifacts, causing signal void and image distortion in the area surrounding the implant.(27,28) While minor artifacts caused by dental implants have been reported in limited areas around the implants in T1-weighted and T2-weighted images,(29) MRI artifacts can be more significant when titanium blade dental implants were placed near the orbital area after surgical treatment for oncological diagnosis.(30) The susceptibility of metallic dental implants compared to neighboring tissue results in signal void and distortion, which can impair image quality in the area of interest for clinicians.(17,31) Furthermore, there is a reported case involving the surgical failure of an MRI deep brain stimulation patient caused by a neodymium magnetic dental implant-supported overdenture. The distortions in areas closer to the dental magnets measured as large as 11-22 mm, resulting in postoperative lead location errors of 5.4 mm on the right side and 2.7 mm on the left side from the intended targets, respectively.(32) This could be implied that the greater the differences in magnetic susceptibility between the metallic dental materials and surrounding tissues, the stronger susceptibility artifacts are presented.(16,33)

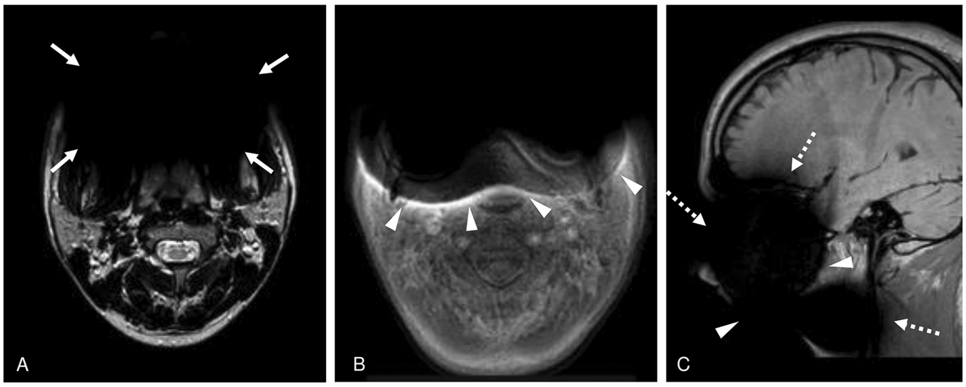

Figure 3: Various types of artifacts caused by metallic dental materials presenting in 1.5 T-MR images: A, an axial T2-weighted image (WI) presents a black area at anterior region of the jaw due to loss of MR signal (solid arrows); B, an axial T1-WI with fat suppression presents loss of fat saturation around the metal-related artifacts (arrowheads); C, a sagittal T1-WI presents displacement artifacts including a large black area of signal loss, geometric distortion (dashed arrows), and enhanced rim of signal pile-up artifact (arrowheads).

Safety concerns of dental implants in the MRI environment

With the increasing prevalence of dental implants in various age groups, a growing number of patients are required to undergo MRI examinations. However, the presence of metallic implants and other medical devices can introduce risks due to the creation of artifacts and MRI-related heating, raising concerns about patient safety in MRI applications.[34,35]

To address these safety concerns, the U.S. Food and Drug Administration (FDA), in collaboration with the MR Task Group of the ASTM International Committee F04 on medical and surgical materials and devices, has developed standardized tests and labeling terms for medical devices and dental implants used in MRI environment (ASTM F2503).[36,37]

These new MR labeling terms and associated icons help differentiate the safety status of different items in or near MR environments.[34] The associated symbols, definitions, and examples of dental materials are described in Figure 4.

The impact of static magnetic fields on dental materials has been extensively studied to verify their safety in the MR environment in terms of thermal changes, dislocation of prostheses, and artifact formation, among other factors. Concerning heating effects, RF exposure dose is commonly measured and expressed as Specific Absorption Rate (SAR), representing the absorbed electric power of RF per unit mass of body weight (W/kg).[38] Standards set by organizations apart from the ASTM (ASTM F2182-02a)[39] like the International Electrotechnical Commission (IEC) and the Japanese Industrial Standards (JIS) help regulate SAR values. Although some metallic objects involved in MR procedures have been observed to cause minor temperature changes,[30] it has been shown that magnetic dental attachments with castable alloys under 3T MRI produce temperature elevations of only 1.42°C, which is below the heat-pain threshold of oral mucosa, ensuring patient safety.[40]

Regarding prosthesis dislocation, metallic dental materials are considered safe if the deflection angle is less than 45° according to the ASTM standard (ASTM F2052).[41] Dental luting cement's retention forces further contribute to preventing prosthesis dislodgement under the MRI environment.[40] A study on different metallic dental materials at different MRI field strengths has shown minimal deflection angles, ensuring the stability of dental prostheses.[42] Metallic dental implants, including coping and implants, do not exhibit apparent translational attraction or heating, meeting the ASTM standards for magnetically induced displacement and RF heating at 3T MRI.[42,43]

Artifact formation is another aspect of concern, with all metallic objects causing artifacts in MRI images. Orthodontic brackets, nickel-chromium materials, and titanium dental implants are among the most susceptible to magnetic fields.[44] While dental crowns cause minimal artifacts, orthodontic appliances, such as orthodontic devices and steel alloy arch wires, can lead to significant image distortions and obstruction of critical anatomical details[17,45,46], as displayed in Figure 5. Consequently, it is crucial to avoid the presence of stainless-steel orthodontic appliances in the oral cavity during MRI procedures to ensure image quality.[47]

Despite causing artifacts, titanium-based implants have been shown to cause minimal visualization disturbance and do not significantly affect examination and diagnosis[17,48,49], as shown in Figure 6. Although the possible influences of static magnetic fields and interactions of dental materials or devices have been investigated, no reports of injuries caused by dental materials during MRI procedures have been documented to date.

Symbol	Definition	Example materials
MR safe (MR)	This term applies to items composed of nonmagnetic, nonmetallic, and nonconducting materials, which pose no hazard in all MR environments.	Dental materials like dental amalgam, gutta percha points, and most dental implants fall under the category of MR safe items.
MR conditional (MR)	Items classified as MR conditional have been shown to pose no known risks in specified MR environments under specific conditions of use. Any conditions of concern affecting safety must be described.	Dental castable alloys, stainless steel keepers, and certain dental implants are examples of materials falling under the MR conditional category.
MR unsafe (MR)	This term is used for materials known to pose hazards in all MR environments.	Dentistry-related devices like ferromagnetic scissors and palladium-clad magnets fall under the MR unsafe category due to their magnetic properties.

Figure 4: MR labeling terms and icons used for implants and medical devices (reprinted with permission from ASTM F2503-20 Standard Practice for Marking Medical Devices and Other Items for Safety in the Magnetic Resonance Environment, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard can be obtained from ASTM, www.astm.org.).

Figure 5: Artifacts due to stainless steel orthodontic appliances. A, CBCT panoramic reformatted image shows fixed orthodontic appliances in both maxillary and mandibular arches; B, Axial T2-weighted image spin-echo of the same patient illustrates severe artifacts at the oral cavity extending to ramus of the mandible, masseter muscles, and left pterygoid muscle causing signal loss (black area) and image distortion; C, Sagittal 3D proton density-weighted image illustrates a dark area of signal loss in both oral cavity, orbital area, as well as frontal lobe and oropharyngeal area.

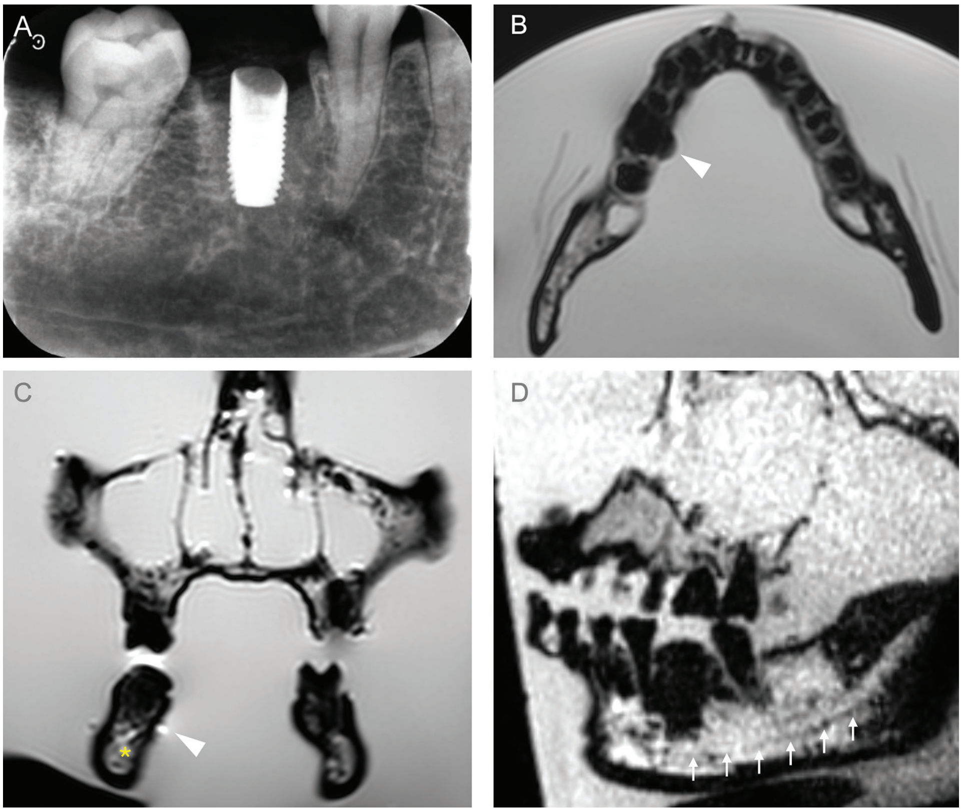

Figure 6: Artifacts caused by dental implants placed in a dry skull. A, a titanium dental implant was placed at the mandibular right first molar area of a dry skull as shown in a periapical radiograph; B, axial T1-weighet image (WI) shows artifacts limited within the mandibular alveolar process; C, coronal T2-WI illustrates a dark area of artifact (arrowhead) extending above the inferior alveolar canal (asterisk); D, sagittal ultrashort echo-time demonstrates the dark artifact above the inferior alveolar canal (arrows).

Safety Considerations for Patients with Titanium Implants

Concerns about patient preparation prior to MRI examination

In 2019, the International Society for Magnetic Resonance in Medicine (ISMRM) released an update and expert consensus addressing the primary safety, screening, and scanning concerns related to MRI examinations. This comprehensive report also includes adverse event reports for each device category, offering practical recommendations to the MRI community.(50) Notably, titanium, being a paramagnetic material, remains unaffected by the magnetic field of MRI, resulting in a very low risk of complications for patients with titanium implants, affirming the safe use of MRI in patients with implants.(51) However, caution is advised when dealing with strong ferromagnetic metals incorporated into dental implants, such as overdenture magnets, stainless steel brackets, and wires. It is recommended to remove these components before undergoing an MRI examination to mitigate potential risks. To ensure patient safety, thorough screening should be conducted, evaluating the possible hazards of unwanted incidents or artifacts that may occur during MRI procedures. For further information, all resources and recommendations are available online on http://www.mrisafety.com/ (Shellock R&D Services, Inc., CA, USA).

Metal artifact reduction strategies

Metal artifact reduction sequence (MARS) has been developed to improve image quality by minimizing the size and intensity of susceptibility artifacts from magnetic field distortion. It is based on view angle tilting (VAT) and increasing gradient strength. MARS is compatible with any spin-echo sequence without adding extra image acquisition time.(30)

Conventional MARS can be achieved by selecting suitable prostheses, such as standard titanium implants at 1.5T instead of 3T MRI. Additionally, adjustment of basic MR sequence parameters, such as voxel size, three-dimensional (3D) spatial encoding, a high-resolution matrix, and using multishot spin-echo (SE) or fast/turbo SE (FSE/TSE) sequences instead of gradient-echo (GRE) sequences, can further refine the MR image(52,53), as displayed in Figure 7. GRE sequences induce artifact volume due to signal intensity loss from intravoxel dephasing in the magnetic field inhomogeneity area.(53) Consequently, using TSE sequences is preferable to generate fewer artifacts than GRE with its high spatial resolution, high readout bandwidth(54), as well as its compatibility with diffusion-weighted imaging (DWI). This ultimately leads to better image quality, especially when compared to single-shot echo-planar imaging-based DWI (EPI-DWI).(55)

Standard methods of fat suppression technique, such as short tau inversion recovery (STIR), have been utilized to clarify image areas by eliminating fat signal and chemical shift misregistration. However, STIR may suffer from relatively low signal-to-noise ratio (SNR) and result in impaired anatomical details. Improved SNR and fat suppression can be achieved by using the DIXON technique, but it is susceptible to artifacts near implants.(27)

To overcome the limitations of conventional methods, advanced sequences have been commercially available, such as Orthopedics-Metal Artifact Reduction (O-MAR) from Philips (Best, Netherlands), and WARP from Siemens (Erlangen, Germany). These sequences are operated by combining conventional MARS with VAT. Additionally, multiacquisition variable-resonance image combination (MAVRIC) and MAVRIC-SL from General Electric (GE, Milwaukee, WI, USA) have been developed.(27,53,56,57) Below are some examples of these novel techniques:

1. VAT is used to correct in-plane distortion via slice-selection gradients concurrently with conventional readout gradients, in combination with the slice encoding for metal artifact correlation (SEMAC) technique. However, VAT-induced blurring in the image is a consequence of the shearing effect within an image slice. The reduction of through-plane distortion is a main limitation of VAT.(53,56) Consequently, SEMAC has been developed based on a 2D TSE sequence to reduce through-plane distortion using additional phase encoding in the slice selection. Signals excited in the wrong slice positions are corrected. SEMAC demonstrates superiority in metallic artifact reduction compared to VAT, standard MR sequences, and high bandwidth protocols.(53,56) The combination of VAT and SEMAC has been shown to reduce artifacts related to titanium implants by up to 43% *in vitro* and up to 80% *in vivo* study in 3T MRI. The standard TSE sequence with VAT and SEMAC has also been effective in reducing artifacts from titanium orthodontic appliances in 1.5T MRI.(58,59) When combined with WARP, both VAT and SEMAC showed a reduction of 69.1% in dental implant artifacts relative to inferior alveolar nerve (IAN) in comparison to GRE sequences in both volunteers and patients with postoperative IAN impairment.(54) Furthermore, SEMAC can be used with ultrashort echo time (UTE) sequences to reduce susceptibility artifacts resulting from osseous-fixation titanium plates in 3T MRI.(60)

2. MAVRIC, a nonselective 3D acquisition technique, prevents slice-direction displacement using phase encoding and decreases susceptibility artifacts by combining multiple image datasets of wide range frequency offsets near the metallic implant into a single image. MAVRIC can further minimize distortion compared to conventional TSE techniques and has the advantage of reducing scan time. However, image blurring is a limitation of MAVRIC.(53,56) The use of MAVRIC and MAVRIC-fast sequences combined with hybrid positron emission tomography (PET)/MRI resulted in artifact reduction from dental implants in comparison to conventional GRE sequences (LAVA-Flex) and T1-WI FSE.(52) This modified PET/MRI technique is presented as an excellent method for oropharyngeal cancer examination.

In the context of dental implants, SEMAC and MAVRIC techniques in MRI can significantly reduce metal-related artifacts, but with increased scan times. These techniques require additional phase-encoding steps, leading to scan times 2-3 times longer than conventional MRI sequences.(61-63) The prolonged scan duration can impact patient comfort and compliance. Extended time in the MRI machine may increase the risk of involuntary movements, such as swallowing or shifting positions, potentially introducing new artifacts. It can also exacerbate claustrophobia and anxiety in some patients particularly those with pre-existing conditions or previous negative experiences with MRI, further complicating the imaging process. From a clinical perspective, the increased scan times can reduce throughput and efficiency, potentially leading to longer wait times for patients and impacting clinic workflow and efficiency for healthcare providers.(63)

To mitigate the increased scan time, strategies such as optimizing sequence parameters or using parallel imaging techniques may be employed.[61,62] Healthcare providers should carefully consider these factors when selecting the most appropriate imaging strategy for patients with dental implants, balancing the need for artifact reduction with practical clinical considerations.

Apart from postprocessing scan sequences, modifying the titanium implant structure is another artifact reduction method. The material composition of dental implants and implant-supported single crowns significantly influences artifact volumes on MRI. Crowns containing high amounts of cobalt, chromium, or tungsten were associated with large artifact volumes.[64] A study modified Ti-6Al-4V specimens to have a porous structure, which decreased the density of the implants and resulted in a reduction of susceptibility artifacts compared to solid materials in the 3T MRI system. Decreasing the mass of octahedral and diamond lattice structures by half reduced the artifact volume by approximately 50%.[65] Furthermore, the fewest MR artifacts were observed in zirconia implants combined with monolithic zirconia crowns compared to titanium implants combined with different single crown materials on 3T MRI.[21] Zirconia implants have been shown to produce fewer artifacts than titanium-based implants, especially in T1-WI.[9,66-68] From these previous reports, it is suggested that manufacturing dental implants with titanium can be replaced with alternative non-metallic substances for MRI artifact reduction. Techniques suggested to reduce metal-induced artifacts are shown in Table 2.[69]

Conclusions and Recommendations

Our review of dental implant artifacts in MRI and their safety has revealed significant insights into the potential challenges and solutions in clinical practice. Dental devices, including dental implants, dental crowns, and orthodontic appliances, can cause artifacts in MRI due to their high magnetic susceptibility, particularly in materials like iron, stainless steel, and cobalt-chromium. These artifacts can vary in size, ranging from localized distortions around the materials to larger artifacts obscuring neighboring structures.

Clear communication between dentists, radiologists, and MRI technicians is essential for optimal patient care and imaging outcomes. Dentists should be concerned with the following before their patients undergo MRI:

1. Providing a detailed dental history, including the types and materials of implants, crowns, and other dental works.

2. Advising patients to remove removable dentures or orthodontic devices before the MRI procedure.

3. Informing radiologists about the presence and location of any fixed dental prostheses that might affect imaging.

While dental implants introduce minute but detectable artifacts into MRI imaging, their removal prior to MRI examinations is impractical. Therefore, optimizing image acquisition and processing techniques to minimize artifact size becomes paramount. Titanium dental implants are generally considered safe in the MRI environment due to their paramagnetic nature, conforming to ASTM

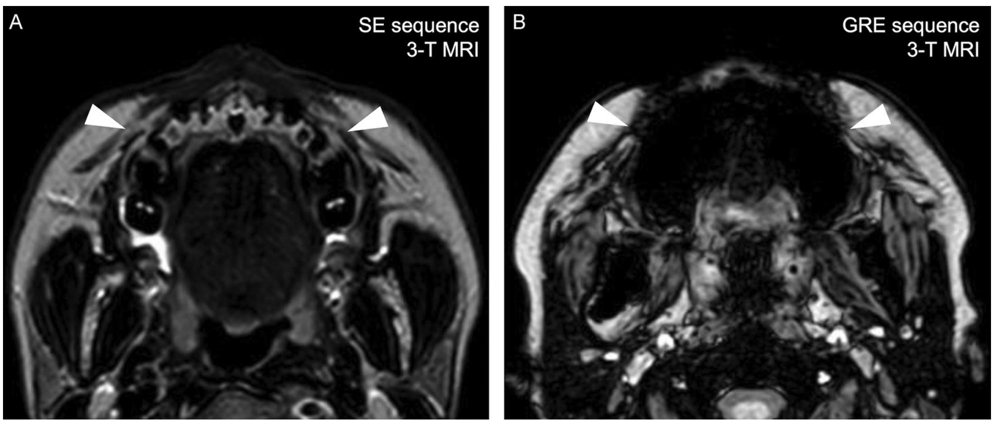

Figure 7: Artifacts according to different MR sequence acquisition: A, Spin-echo (SE); B, Gradient-echo (GRE). The areas of signal void present less in SE than in GRE (arrowheads).

Table 2. Suggested techniques to reduce metal-induced artifacts.[54]

Options	Consequences	Limitations
Preprocessing scan		
Use Zirconium (Zr) rather than Titanium (Ti) implant	Lessen metal-related artifacts	N/A
Use 1.5T rather than 3T	Metal artifact reduction	Machine availability and specification
Postprocessing scan		
Increase the read-out bandwidth	In-plane distortion reduction	Signal-to-noise (SNR) decrease
Reduce the slice thickness	Trough-slice distortion reduction	
Use fast spin echo (TSE or FSE) instead of gradient echo (GRE) sequence	Signal loss reduction	Anatomical evaluation degradation such as vessels, nerves, salivary gland
Use fat suppression technique such as short tau inversion recovery (STIR) or Dixon technique	Homogeneous fat suppression	SNR decrease
Use a metal artifact reduction sequences or combination of such sequences such as VAT-SEMAC, OMAR, WARP, MAVRIC or MAVRIC-SL	In-plane distortion reduction and trough-slice distortion reduction	Not available in all MR scanners, acquisition time increase

standards. However, even titanium can produce limited artifacts, and trivial ferromagnetic components can cause undesirable metal-related artifacts affecting visualization. Two primary categories of artifact reduction techniques have been identified:

1. Utilizing improved porous structures of titanium or alternative materials like zirconia.

2. Adjusting basic MR parameters and employing advanced sequences, such as increasing readout bandwidth, reducing slice thickness, choosing SE or FSE over GE, and employing STIR or DIXON for fat suppression.

Advanced methods like VAT, VAT-SEMAC combination, and MAVRIC have shown promise in reducing artifacts, although their applicability may be limited in certain MR scanners.

Continuous efforts should be made to develop suitable dental implant materials and optimize MRI sequences to overcome susceptibility artifacts and enhance imaging quality. The collaboration between dental practitioners, radiologists, and MRI technologists is mandatory in refining techniques and ensuring patient safety during MRI examinations involving dental devices.

In conclusion, while dental implant artifacts can present challenges, their safety under MRI is well-established. Advancements in reducing artifacts offer promising solutions for improving the overall quality and reliability of MRI imaging in patients with dental devices. Effective communication among healthcare professionals is key to navigating these challenges and providing the best possible care for patients.

Acknowledgments

We would like to clarify that we utilized generative artificial intelligence technology for language correction purposes in the preparation of this manuscript.

Confliets of Interest

The authors declare no conflict of interest in the study.

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Review Article

The Association Between Periodontitis and Respiratory Diseases: A Comprehensive Review

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Abstract

Periodontal disease is a significant factor in periodontal destruction, primarily initiated by a multi-bacterial infection that progresses through a cascade of chronic inflammatory responses. This persistent inflammation not only affects periodontal tissues but also has systemic implications, heightening the risk of various systemic diseases. Among these, respiratory diseases—which are closely linked to inflammatory processes, are of particular concern. Conditions such as asthma, pneumonia, chronic obstructive pulmonary disease (COPD), and lung cancer have been increasingly associated with the chronic inflammatory state induced by periodontitis. The aim of this review was to elucidate the mechanisms underlying the association between periodontitis and respiratory diseases. Chronic periodontitis creates a state of systemic inflammation that can disseminate through the bloodstream, impacting distant organs, including the lungs. Emerging evidence from recent studies highlights the role of periodontitis in both the initiation and exacerbation of respiratory diseases. Microbial pathogens associated with periodontitis, such as *Porphyromonas gingivalis*, can be aspirated into the lower respiratory tract, leading to either direct infection or modulation of the local immune response. This can increase susceptibility to respiratory conditions such as pneumonia and exacerbate pre-existing diseases like COPD and asthma. In summary, the relationship between periodontitis and respiratory diseases is complex and multifaceted, involving direct microbial interactions, systemic inflammation, and immune modulation. Understanding these connections is crucial for developing integrated therapeutic strategies that address both oral and respiratory health.

Keywords: inflammation, periodontitis, respiratory disease

Introduction

Periodontitis is a chronic inflammatory disease resulting from an imbalance between pathogenic microorganisms and the host's defense mechanisms, leading to the destruction of the tissues surrounding the tooth. Clinically, periodontitis is characterized by gingival inflammation, loss of connective tissue and alveolar bone, increased probing depths, formation of periodontal pockets, and gingival recession.(1) Periodontitis has been recognized as a global public health burden, contributing significantly to tooth loss in the adult population worldwide.(2) The prevalence of total periodontitis (including mild, moderate, and severe forms) was reported to be 42%, based on full-mouth examinations conducted among the adult U.S. population during the 2009–2014 cycles of the National Health and Nutrition Examination Survey (NHANES).(3) Several predisposing factors associated with periodontitis have been identified, including tobacco smoking, poor oral hygiene, hormonal changes in females, age, genetic predisposition, and systemic diseases.(4) Recent studies have reported a bidirectional association between periodontitis and various systemic diseases, including cardiovascular disease, metabolic syndrome, osteoporosis, type II diabetes, gastrointestinal and colorectal cancer, as well as respiratory diseases.(5) It has been suggested that the presence of periodontal-related pathogens and their metabolic by-products in the oral cavity may trigger the host immune response beyond the oral cavity, potentially contributing to the development of life-threatening systemic diseases.(6)

Respiratory diseases have been recognized as a leading cause of increased morbidity and mortality in populations worldwide.(7) A recent study using data from the Sixth Korea National Health and Nutrition Examination Survey (KNHANES) conducted in 2014 evaluated the prevalence of periodontitis and investigated its association with reduced pulmonary function. The findings suggest that approximately 60% of patients with periodontitis are affected by respiratory conditions.(8) Furthermore, the severity of these respiratory diseases correlates with the progression of periodontal infection.(9)

It has been suggested that the continuity between the oral cavity and the respiratory tract may serve as a potential reservoir, where bacteria harbored in the mouth can be transmitted to the airway and lungs. Although the precise mechanisms underlying the transmission of periodontitis-associated bacteria to the respiratory tract remain debated, two potential mechanisms have been proposed: 1) direct bacterial transmission via hematogenous spread and aspiration(10) and 2) indirect inflammatory responses of the respiratory system caused by periodontitis-associated bacteria and their by-products.(11) Therefore, oral microorganisms can readily impact the respiratory system, potentially leading to the development of airway infections and exacerbating lung inflammation.

This review article examined the relationship between periodontitis and four major respiratory diseases. This review also addressed the inflammatory mechanisms that play a crucial role in respiratory diseases, the pathophysiological mechanisms of periodontitis, and the impact of periodontitis-related microorganisms and their by-products on the pathophysiology and severity of asthma, pneumonia, chronic obstructive pulmonary disease (COPD), and lung cancer.

Periodontal disease

Periodontitis is a chronic inflammatory disease attributed to hyper-inflammatory responses elicited by dysbiotic bacterial communities or dental biofilms in conjunction with host immune reactions. The microbial etiology of periodontitis is currently explained by the polymicrobial synergy and dysbiosis (PSD) model. In this model, the gingival crevice is populated by diverse, compatible microorganisms that form heterotypic communities or biofilms. Under homeostatic conditions, these communities maintain equilibrium with the host, allowing the host to regulate bacterial virulence factors, such as proteases and toxins, produced by these microorganisms. However, when keystone pathogens, including *Porphyromonas gingivalis, Treponema denticola, Tannerella forsythia, Fusobacterium nucleatum, Prevotella intermedia,* and *Aggregatibacter actinomycetemcomitans,* colonize the site—even at low abundance—they promote the growth of other bacteria, alter microbiota composition, and modify metabolic activities. This disruption ultimately shifts the microbial balance towards dysbiosis.(12) Dysbiosis is a state in which previously commensal microbiota act as proinflammatory pathobionts. As these dysbiotic communities proliferate, they can impair host immune surveillance, ultimately leading to the destruction of periodontal tissues.(13)

Porphyromonas gingivalis is recognized as a key causative bacterium in periodontal disease, and its abundance can be used to predict the progression of chronic periodontitis. When the periodontium is colonized by dental biofilms, keystone pathogens such as *Porphyromonas gingivalis* produce various virulence factors, including capsules, fimbriae, proteases, and lipopolysaccharides (LPS), which contribute to the onset of dysbiosis.(14) LPS is a crucial component of the outer membrane of Gram-negative bacteria, playing a significant role in activating the innate immune response in damaged gingival cells. LPS induces the release of cytokines such as IL-1, IL-6, IL-10, IL-12, and TNF-α. The elevated levels of LPS-inducible cytokines stimulate the recruitment of neutrophils and macrophages from the gingival epithelium, leading to immune-inflammatory destruction of periodontal tissues.(15)

It is well established that chronic periodontitis indirectly induces the release of a variety of inflammatory mediators, including cytokines, histamine, prostaglandins, substance P, matrix metalloproteinases (MMPs), bacterial toxins, and enzymes from both host and bacterial cells. These mediators trigger inflammatory responses to combat periodontal infections. Additionally, several studies have reported that these inflammatory mediators can be transmitted directly or indirectly from the oral cavity to distant organs, adversely affecting various systemic diseases, such as diabetes, cardiovascular disease, pulmonary disease, and chronic kidney disease.(16) Moreover, there is evidence suggesting a possible association between periodontitis and an increased risk of malignancy, both in nearby organs (e.g., oral cancer) and in distant organs (e.g., pulmonary and pancreatic cancers).(17)

Inflammation and respiratory diseases

Inflammation is a physiological response of the immune system that can be triggered by various harmful factors, including pathogens, damaged cells, and toxic compounds. This inflammatory response is crucial in several airway pathologies, including asthma, pneumonia, and COPD.(18) Additionally, inflammation plays a critical role in the progression of lung cancer, contributing to the neoplastic process by promoting tumor proliferation, invasion, migration, and metastasis.(19)

The lungs, as organs frequently exposed to the microbiome through both direct and indirect pathways, exhibit distinct microbial profiles. Studies utilizing culture-independent techniques have shown that a healthy lung predominantly harbors phyla *Bacteroidetes* and *Firmicutes*. In contrast, pathological conditions such as asthma, pneumonia, COPD, and malignancy are associated with alterations in the lung microbiome. These changes are driven by dynamic shifts in the microbial ecosystem, influenced by factors such as alterations in oxygen tension, blood circulation, and the deposition of effector inflammatory cells. Notably, the altered microbiome in the airways can trigger inflammatory responses and contribute to the pathogenesis of respiratory diseases.(20)

In the context of respiratory inflammation, various types of inflammatory cells are involved. Dendritic cells and macrophages form the first line of defense by recognizing a wide range of pathogens. Once a dendritic cell identifies, ingests, and processes an antigen, it migrates to the lymph nodes, presenting the antigen to resident T cells and thereby initiating an immune response.(21) Macrophages play a crucial role in regulating both acute and chronic inflammatory responses. Alongside dendritic cells, they are capable of phagocytosing bacteria, particulates, and apoptotic cells. Additionally, macrophages are a primary source of cytokines, chemokines, and other inflammatory mediators that either promote or inhibit the immune response.(22) Neutrophils serve as the second line of defense. During pulmonary infections, they migrate from the pulmonary capillaries into the air spaces, where they phagocytose pathogens. Following phagocytosis, neutrophils utilize reactive oxygen species, antimicrobial proteins (such as bactericidal permeability-inducing protein and lactoferrin), and degradative enzymes (such as elastase) to eliminate ingested microbes.(23) Lymphocytes are distributed throughout the airways and lung parenchyma. T lymphocytes are responsible for cell-mediated immunity, while B lymphocytes contribute to humoral immune responses through the synthesis of antibodies. T lymphocytes are divided into two major subsets: CD4+ and CD8+ cells. CD4+ T lymphocytes, also known as T helper cells, are further classified into type 1 T helper cells (Th1) and type 2 T helper cells (Th2). Th1 cells are involved in cellular immune responses targeting intracellular antigens, secreting cytokines such as interferon-gamma (IFN-γ) and tumor necrosis factor-alpha (TNF-α). In contrast, Th2 cells mediate humoral immune responses to extracellular antigens, releasing various cytokines including IL-4, IL-5, IL-9, and IL-13.(18) An imbalance in the concentrations of these cytokines can exacerbate immune responses and contribute to the pathogenesis of several respiratory diseases.

Association between periodontitis and respiratory diseases

Given the continuity between the oral cavity and the respiratory tracts, exploring the relationship between the oral microbiota and the lungs can provide insight into the pathophysiology of lung diseases in contrast to healthy states. There is an increased risk of respiratory disease associated with poor oral health. Improving oral health has been linked to a reduction in respiratory events among high risk elderly patients in nursing homes and intensive care units.(24) The most common bacterial strains in the oral cavity include *Streptococcus, Lactobacillus,* and *Prevotella,* with *Porphyromonas gingivalis* being the key pathogen typically associated with periodontal infections.(6) Oral microorganisms have also been detected in the respiratory tract. A microaspiration study using bronchoalveolar lavage (BAL) samples from healthy lungs revealed that oral microorganisms such as *Prevotella* and *Veillonella* are enriched in lower airway samples, and these microbiota are linked to increased numbers of lymphocytes and neutrophils.(25) Similarly, a study has demonstrated that the oral and lung microbiomes are largely homogenous. The finding revealed that the bacterial communities of healthy lungs share a significant overlap with those of the mouth.(26)

Current studies have demonstrated that chronic periodontitis is associated with not only respiratory diseases but also a range of other systemic conditions, including cardiovascular diseases, metabolic syndrome, osteoporosis, type II diabetes, and malignancies of various organs. It is clear that periodontitis-induced immune responses contribute to these systemic diseases through both hematogenous dissemination and trans-tracheal routes (Figure 1). Through the hematogenous route, periodontitis-related microorganisms and their by-products can travel from the oral cavity to the respiratory tract via the bloodstream, directly triggering the pathophysiology of the lungs.(27) In the transtracheal route, high levels of periodontitis-related microbiota in saliva can be aspirated into the lungs, leading to pulmonary bacterial

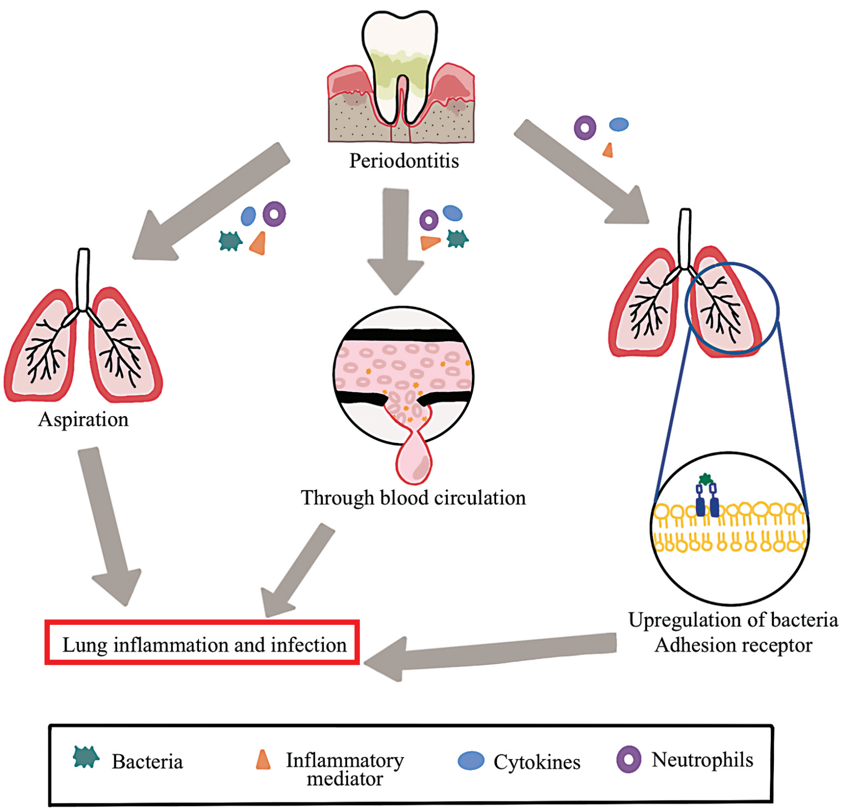

Figure 1: The routes through which periodontal pathogens can reach the respiratory tract include aspiration, hematogenous spread, and indirect mechanisms involving alterations in the respiratory epithelium and the upregulation of adhesion receptor.

colonization.[28] In addition to the direct bacterial transmissions mentioned, periodontitis-related bacteria and their by-products can indirectly induce alterations in the respiratory epithelium, thereby increasing susceptibility to bacterial infections.[29] In cases of untreated periodontal disease among high-risk individuals, a wide range of cytokines and other biologically active molecules continuously released from periodontal tissues and peripheral mononuclear cells may modify the respiratory epithelium. This can facilitate colonization by respiratory pathogens through the upregulation of adhesion receptor expression on mucosal surfaces, ultimately leading to infection.[30]

Periodontitis and asthma

According to the World Health Organization, asthma affected approximately 262 million individuals in 2019 and was responsible for 455,000 deaths. The prevalence of comorbidities is higher among older adult patients with asthma.[31] Asthma is a chronic respiratory disease triggered by pathogens, irritants, or environmental factors, leading to bronchospasm. It is characterized by reversible airway obstruction, with symptoms including wheezing, shortness of breath, and chest tightness. These symptoms can vary in intensity over time. This condition results in symptoms such as chest tightness, wheezing, and shortness of breath. Upon exposure to stimuli, Th2 cells are activated and release interleukins IL-4, IL-5, IL-9, and IL-13. Additionally, these stimuli promote eosinophilic inflammation and the recruitment of immunoglobulin E (IgE), which further induces the production of inflammatory mediators such as histamine, and cysteinyl leukotrienes. These inflammatory mediators contribute to bronchoconstriction, pulmonary edema, and mucous secretion, which constitute the symptoms of asthma.[32]

Several studies have reported the positive relationship between periodontitis and asthma. A case-control study reported an association between chronic periodontitis and severe asthma, indicating that the risk of asthma induced by periodontitis was three times higher in patients with periodontitis compared to healthy individuals.[33] The associations between subjective oral health status and allergic diseases in adult Korean were also examined. In this study, the adjusted odds ratio (OR) for asthma was 1.48 in individuals with poor oral health compared to those with good oral health.[34] Similarly, another study found that patients in the asthma group had more severe periodontitis, with a greater proportion suffering from stage IV periodontitis. In contrast, stage II and III periodontitis were more prevalent in the non-asthma group. Increased tooth loss, attachment loss, and bone loss were also found among patients using anti-asthmatic drugs.[35] In contrast, A recent meta-analysis found no significant association between periodontal disease and asthma.[36]

Although the mechanism by which periodontitis induces asthma remains unclear, several plausible explanations have been proposed. First, *Prevotella intermedia* is a key periodontal pathogen involved in dysbiotic biofilms. *Prevotella intermedia* and its associated pathogens contribute to periodontitis and stimulate the release of proinflammatory cytokines, hydrolases, collagenases, and MMP, thereby exacerbating periodontal breakdown.[37] Second, certain MMPs, including MMP-1, MMP-2, MMP-3, MMP-8, and MMP-9, are prominently present in allergic and asthmatic patients.[38] These MMPs play a role in mediating cell trafficking and remodeling of the pulmonary tract.[39] And lastly, the prevalence of gingivitis in individuals with asthma is likely related to alterations in immune responses and habitual mouth breathing. Although the role of allergies in periodontal disease is not yet fully understood, IgE-mediated mechanisms contribute to periodontal tissue destruction. Notably, similar cytokines are involved in both periodontal disease and airway inflammation, with elevated levels of IL-5 and IL-6 observed in patients with asthma and periodontitis. The inflammatory processes in periodontal disease and asthma exhibit similar pathophysiological mechanisms, which may partially explain the high frequency of periodontal inflammation in individuals with asthma.[40] The continuity between the oral cavity and the trachea allows bacteria and periodontopathogens to reach the airways through both blood circulation and aspiration. The release of cytokines, mediators, and toxic by-products sensitizes the pulmonary epithelium, leading to local inflammatory responses (Figure 2).

Periodontitis and pneumonia

Pneumonia is an acute pulmonary inflammation caused by various infectious microorganisms, including fungi, viruses, and bacteria. Bacterial pneumonia is the most common and life-threatening form of the disease, particularly in adults aged 65 years and over, and children aged up to two years. According to the Global Burden of Disease Study 2015, lower respiratory tract infection is the leading cause of infectious disease death, and the fifth most common cause of death overall and those with comorbidities.[41]

Pneumonia is characterized by symptoms such as cough, shortness of breath, and sharp or stabbing chest pain, particularly during deep breathing. The most common microbial pathogens responsible for pneumonia include *Streptococcus pneumoniae, Haemophilus influenzae, Mycoplasma pneumoniae,* and *Klebsiella pneumoniae.*[42] In response to bacterial infections, alveolar macrophages, which serve as a primary defense mechanism in the respiratory system, engulf pathogens through endocytosis. This process subsequently triggers the release of proinflammatory cytokines, such as IL-1, IL-8, and TNF-α, leading to localized inflammation at the site of infection. This respiratory defense mechanism is thought to induce localized lung inflammation, which may progress into pneumonia.[43]

It is well established that there is an association between periodontitis and pneumonia, with dental biofilms contributing to the increased incidence and progression of pneumonia. Periodontitis and pneumonia share common risk factors, including tobacco smoking, stress, and aging. Aspiration is the primary route through which periodontitis contributes to pneumonia.[7] Initially, subgingival microorganisms such as *Porphyromonas gingivalis, Treponema denticola, Tannerella forsythia*, and *Fusobacterium nucleatum* are transmitted to the respiratory tract through aspiration. These periodontitis-associated pathogens colonize the respiratory system, becoming a source of infection that can lead to bacterial pneumonia. Additionally, proinflammatory biomolecules, including IL-1 and TNF-α, present in gingival crevicular fluid from periodontitis, can diffuse into saliva and subsequently be aspirated into the respiratory tract.[44] As a result, periodontitis increases the risk of pneumonia and exacerbates the inflammatory processes that contribute to its progression (Figure 3).

Several studies have demonstrated that periodontitis increases the incidence and accelerates the progression of pneumonia. Pathogenic microorganisms that colonize the oral microbiome have been linked to aspiration pneumonia, particularly in older individuals residing in long-

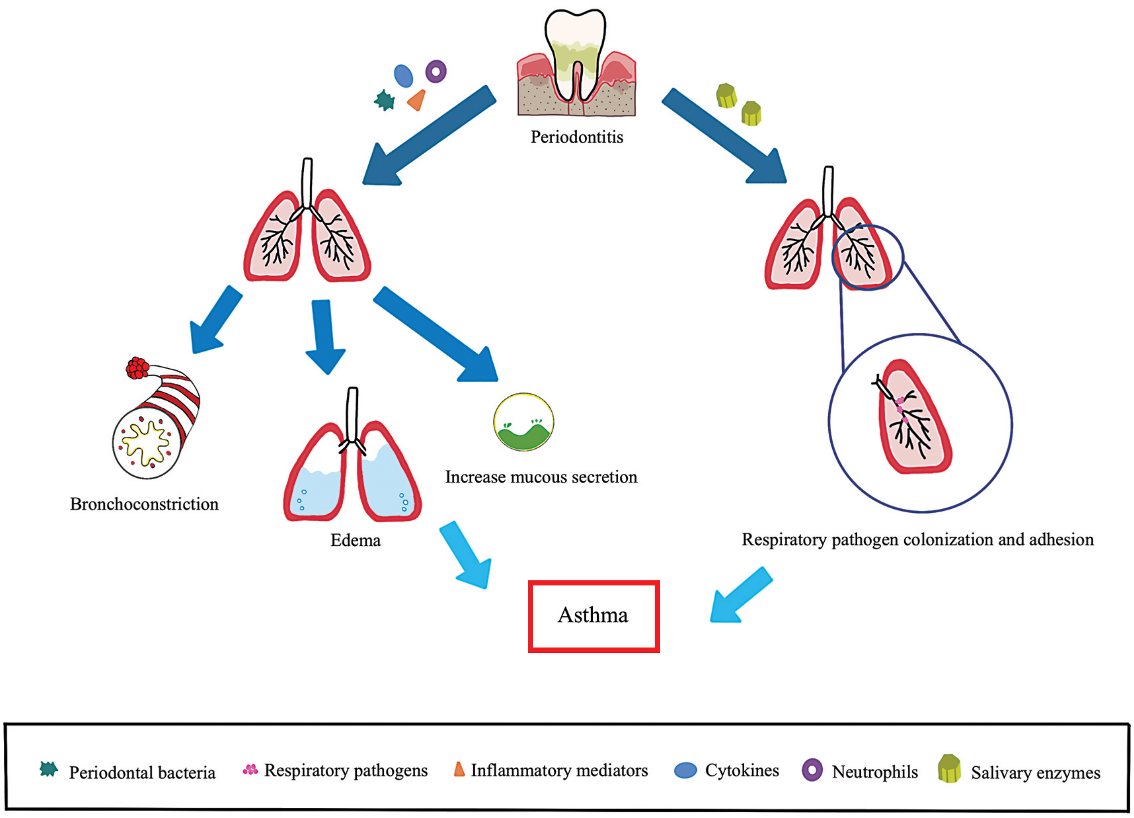

Figure 2: Periodontal and respiratory pathogens, along with inflammatory cells and mediators or salivary enzymes from patients with periodontitis, can reach the respiratory tract through aspiration, hematogenous spread, and indirect mechanisms. These pathways can facilitate the colonization and adhesion of respiratory pathogens, adversely affecting lung health and exacerbating asthma severity.

term care facilities.(44) A nationwide population-based study from 2001-2012 in Taiwan indicated that patients who received periodontal treatment exhibited a significantly lower risk of developing pneumonia compared to the general population.(45) The previous study assessed the impact of periodontitis on pneumonia progression by comparing C-reactive protein (CRP) levels between pneumonia patients and healthy individuals. The CRP levels serve as an indicator of host immune responses, reflecting periodontal tissue destruction. This study have shown that CRP levels were significantly higher in pneumonia patients compared to the control, further confirming the association between periodontitis and pneumonia.(46)

Periodontitis and chronic obstructive lung disease (COPD)

The airflow limitation that characterizes COPD results from a prolonged time constant for lung emptying, which is caused by increased resistance in the small conducting airways and increased lung compliance due to emphysematous destruction.(47) Two hypotheses have been proposed to explain the mechanisms underlying periodontitis-induced COPD (Figure 4). The first mechanism involves aspiration. Periodontitis-associated microorganisms reside in the oral cavity and can be aspirated directly into the respiratory tract. These periodontal pathogens may contribute to the exacerbation of inflammation, airflow limitation, and the degradation of lung structures. Specifically, *Porphyromonas gingivalis*(48) and *Fusobacterium nucleatum*(49) stimulate the gene expression of MUC5AC, a mucin core protein, in primary human bronchial epithelial cells, potentially leading to narrowing of the airway lumen. The second hypothesis suggests that periodontal pathogens act as reservoirs, spreading infection via the bloodstream.(50)

Several studies have reported the association between periodontitis and COPD. Poor periodontal health, as indicated by missing teeth and plaque index scores, was significantly associated with a lower quality of life in patients with COPD.(51) Patients with more severe periodontal infection exhibited a greater risk for COPD compared to those with mild periodontitis or healthy individuals.(52) A meta-analysis revealed a significant association between deteriorating periodontal health

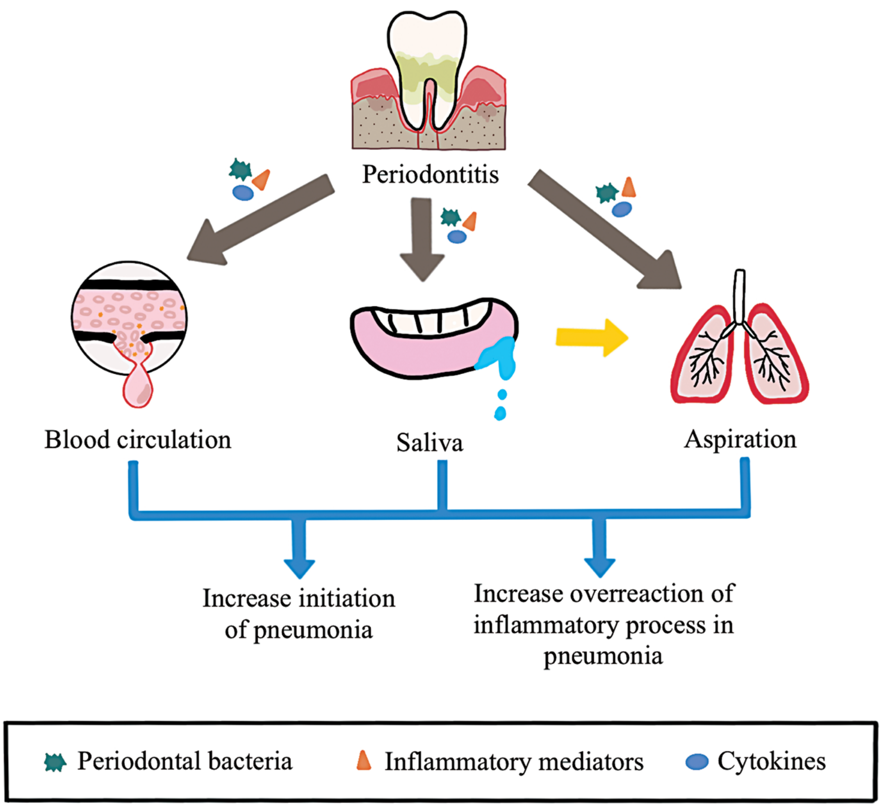

Figure 3: The routes for periodontal pathogens and inflammatory mediators in periodontitis patients to reach the respiratory tract can initiate pneumonia and exacerbate the inflammatory response, contributing to the progression of the disease.

and an increased risk of COPD, encompassing chronic bronchitis and emphysema, with ORs ranging from 1.45 to 4.50. The authors suggested that cigarette smoking may have confounded the findings, as periodontal status was linked to a heightened risk of COPD among current smokers (relative risk [RR] = 1.63, 95% confidence interval [CI] = 1.20–2.21), whereas no such association was observed in never-smokers (RR = 1.19, 95% CI = 0.71–1.98).(53) The recent cross-sectional study in Japan revealed mutual relationships among periodontal disease and its various factors. Probing pocket depth (PPD) was significantly associated with occlusal force in employees with moderate COPD.(54) In contrast, some studies indicate that smoking and aging may significantly influence the outcomes. Their findings revealed that the presence of dentures, missing teeth, oral mucosal disease, and a higher index for decayed, missing, and filled permanent teeth (DMFT) correlated with reduced maximal expiratory flow at 25%. Because periodontitis and DMFT were associated only with age and the amount of smoking, they concluded that much of the association between pulmonary function and poor oral hygiene could be explained by smoking and age.(55)

Since periodontitis and COPD share several predisposing factors, including smoking, age, obesity, socioeconomic status, and living conditions. Dental plaque containing bacteria may contribute to the risk of COPD; therefore, proper attention to tooth brushing and overall oral hygiene may help reduce this risk. Patients with COPD who are undergoing inhaled steroid treatment are advised to use a spacer and rinse their mouths with cold water afterward. Individuals susceptible to COPD should prioritize their oral hygiene, schedule regular dental check-ups, and refrain from smoking.(56)

Periodontitis and lung cancer

Lung cancer is a multifactorial disease influenced by various factors, including behavioral patterns, genetic predispositions, environmental exposures, infections, chronic irritation, and inflammation. Unlike other respi-

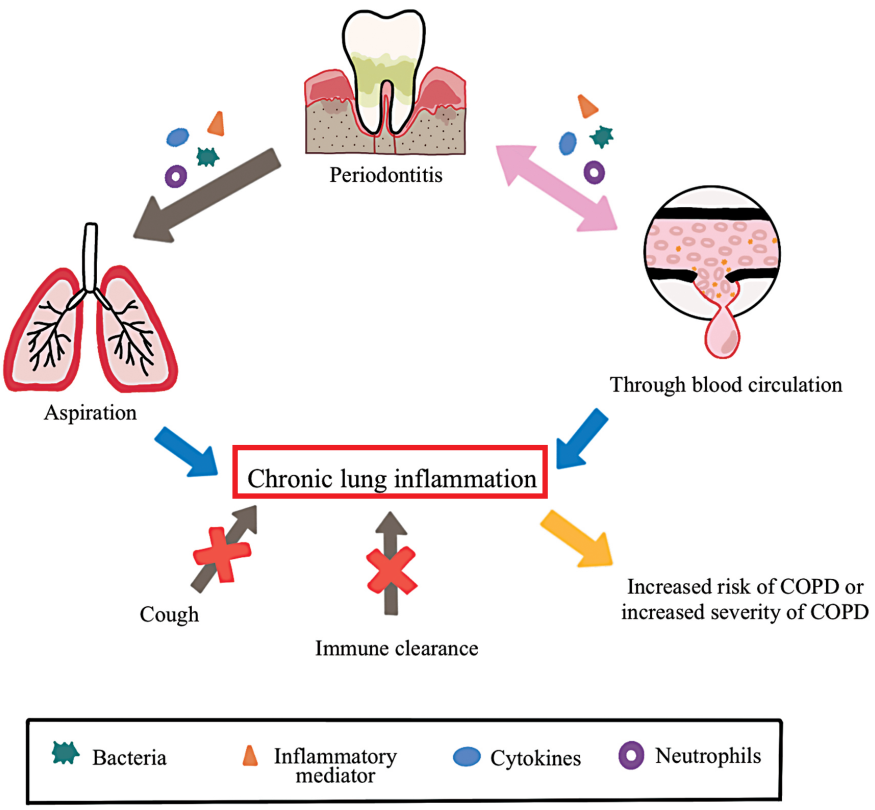

Figure 4: Periodontal pathogens can reach the respiratory tract through aspiration (indicated by brown arrows) and hematogenous spread (indicated by pink arrow), leading to chronic lung inflammation and an increased risk or severity of chronic obstrutive pulmonary disease (COPD). However, the body's natural reflexes, such as coughing and immune clearance, can help mitigate the inflammatory process.

ratory diseases, the relationship between periodontitis and lung cancer appears to be more complex. Current evidence suggests that periodontal pathogens may not directly cause lung cancer but instead contribute to tumorigenesis through inflammatory processes associated with disease progression. The chronic inflammation resulting from periodontitis can lead to systemic changes that create an environment conducive to cancer development. These environment contribute to exacerbated cell proliferation, invasion, and metastasis to other organs.(57) Although inflammation serves to protect the body from injuries, persistent or chronic inflammation can lead to several diseases, including diabetes, cardiovascular disease, musculoskeletal disorders, allergies, COPD, and malignancies.(58) Under normal conditions, inflammatory responses are regulated by a balance between proinflammatory cytokines (e.g., IL-1, TNF-α, IFN-ɣ) and anti-inflammatory cytokines (e.g., IL-1β, IL-10, IL-13). However, when this balance is disrupted, inflammatory cytokines may trigger neoplastic processes and stimulate the proliferation, survival, and metastasis of tumor cells.(59)

Several studies have identified chronic inflammation as a critical factor in the pathogenesis of lung cancer (Figure 5). They have reported the role of inflammation in pulmonary neoplasms. Inflammatory components, particularly the leukocyte population, promote tumor progression through their ability to release various cytokines, chemokines, and cytotoxic mediators, such as reactive oxygen species, MMPs, IFN, TGF-β, natural killer cells, macrophages, myeloid-derived suppressor cells, and mast cells. Consequently, these inflammatory components influence the proliferation of malignant cells, angiogenesis, and tumor metastasis.(60) The previous study demonstrated that *Porphyromonas gingivalis* LPS can synergistically induce the release of IL-6 and IL-8 in the human pulmonary mucoepidermoid carcinoma cell line (NCI-H292). The induced IL-6 and IL-8 activate the phosphorylation of the JNK signaling pathway in NCI-H292 cells, which may

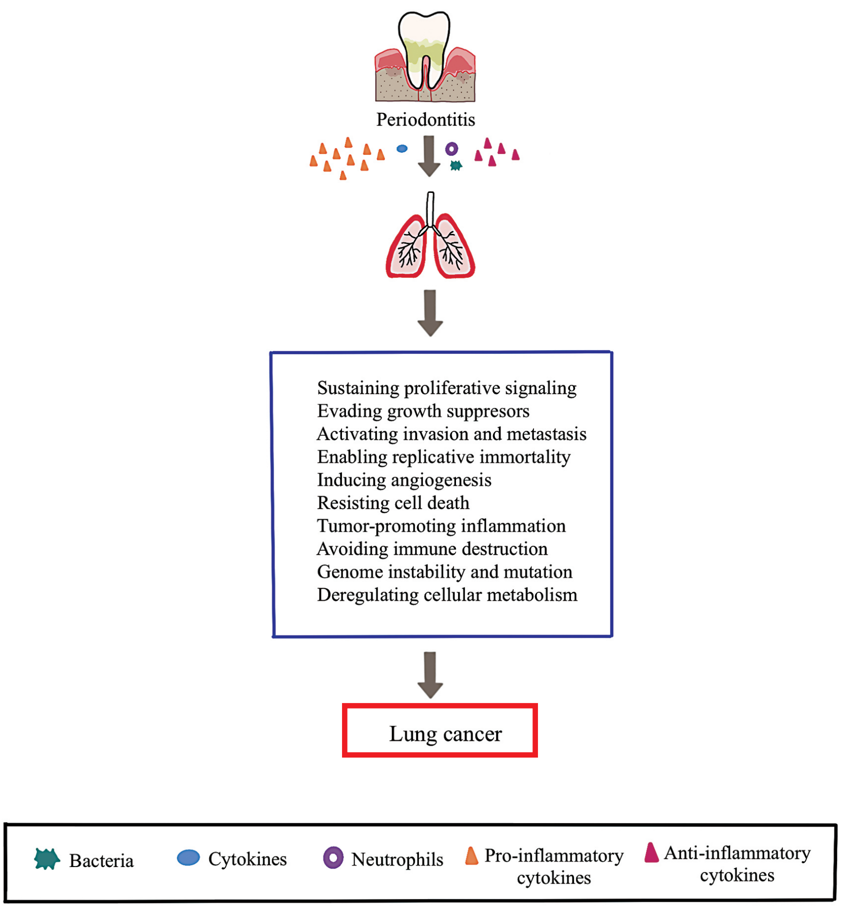

Figure 5: Periodontal pathogens, along with the inflammatory cells and cytokines can promote biological processes that may contribute to the development and progression of lung cancer.

contribute to the development of pulmonary neoplasms.[61] Similarly, another study examined the relationship between IL-6 and IL-8 and pulmonary cancer. The findings revealed that IL-6 and IL-8 were significantly associated with stage I lung cancer patients.[62] In addition, a recent study reported a 13% increase in the risk of total cancer among non-smoking men with periodontitis, while a 45% increase in the risk of total cancer was observed in men with advanced periodontitis.[63] A recent meta-analysis identified an increased risk of lung cancer in patients with chronic periodontitis compared to those without the condition.[64] Additionally, another study concluded that pocket depth may serve as a potential risk factor for lung cancer development. The incidence of lung cancer was observed to be twice as high in patients with increased pocket depth, even after controlling for age and smoking status.[65] It has been suggested that periodontitis may influence the risk of malignancy through systemic immune dysregulation.

Conclusions

This review highlights the positive association between periodontitis and several respiratory diseases, including asthma, pneumonia, COPD, and lung cancer. These conditions share common risk factors, such as smoking, age, and stress, which may influence their development. Periodontopathogens are thought to stimulate inflammatory processes that could increase the risk and progression of respiratory diseases. By elucidating these connections, we aim to enhance awareness among healthcare providers regarding the complexities of these associations. Understanding the relationship between oral health and systemic conditions is crucial for evaluating whether interventions for oral diseases can also prevent systemic diseases. A multidisciplinary approach to treatment is vital for extending healthy life expectancy, improving quality of life, and reducing healthcare costs. However, the precise mechanisms linking periodontal pathogens to respiratory diseases remain unclear, necessitating further research.

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Review Article

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Factors Influencing the Protective Effect of Salivary Pellicle Against Dental Erosion: A Concise Review

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Abstract

Dental erosion is the irreversible loss of dental hard tissue caused by chemical processes without bacteria involvement. Dental erosion prevalence has increased due to extensive consumption of acidic foods and drinks or suffering from gastrointestinal diseases. Salivary pellicle acts as a physical barrier that impedes direct contact between the tooth surface and erosive acids. Furthermore, it is a selectively permeable membrane that controls the diffusion of erosive acids to the tooth surface. Therefore, salivary pellicle can protect the tooth surface from erosive demineralization. The protective effect of salivary pellicle depends on the intraoral location, tooth substrate, thickness, formation time, composition, the pH level of erosive acids, and exposure time. This concise review aimed to provide an overview on factors influencing the protective effect of salivary pellicle against dental erosion.

Keywords: dental erosion, erosive acids, protective effect, salivary pellicle

Introduction

Dental erosion is the dissolution of dental hard tissue by chemical processes due to intrinsic and extrinsic acids without bacterial involvement.(1-3) It causes tooth hypersensitivity, discomfort, imperfect aesthetic of tooth, alteration in tooth shape, and loss of function.(4,5) The prevalence of dental erosion has significantly increased.(6) It is a consequence of extensive consumption of acidic foods and drinks or suffering from gastrointestinal diseases.(4-6)

The salivary pellicle is an important protective factor against dental erosion.(7) It is a thin proteinaceous film that covers the tooth surface.(1) It forms immediately after the exposure of the tooth surface to oral fluids.(8) The salivary pellicle consists of adsorbed salivary proteins, lipids, and carbohydrates.(4,7) The salivary pellicle lubricates the teeth during mastication and speech due to adsorbed salivary proteins such as mucin.(7,9) It is crucial to serve as a lubricant between teeth and other oral structures.(6,7,10) It reduces their friction coefficient.(7,11) Consequently, the lubrication function of the salivary pellicle could reduce tooth wear.(7,11) Besides, the saliva pellicle maintains mineral homeostasis by interacting with various types of saliva.(9,11) It ensures that the calcium concentration on the tooth surface remains a supersaturated state, thus preventing the dissolution of the tooth surface.(7,9,11) Moreover, calcium-binding proteins within the salivary pellicle inhibit the excessive precipitation of calcium and phosphate.(4,7,9,11)

Another important function of the salivary pellicle is protecting the tooth surface from erosive demineralization by serving as a barrier and inhibiting direct contact between erosive acids and the tooth surface.(12,13) The salivary pellicle is a selectively permeable membrane that regulates the acid diffusion rate and modifies the transportation of calcium ion, phosphate ion, and proton.(1,2,14) Thus, it could delay the dissolution rate of the tooth surface from erosive demineralization.(15) Furthermore, the salivary pellicle maintains the level of calcium and phosphate ions between saliva and the tooth surface.(14) These ions can diffuse freely among the salivary pellicle, saliva, and the tooth surface.(16) Consequently, the salivary pellicle plays a crucial role in maintaining the equilibrium between erosive demineralization and remineralization on the tooth surface.(12)

It should be noted that salivary pellicle alone may not have sufficient protective effect.(7) The protective effect of the salivary pellicle depends on many factors such as its intraoral location, tooth substrate, thickness, formation time, composition, pH level of erosive acids, and exposure time of erosive acids.(7,15,17,18) Understanding the role of these factors is beneficial to increase the protective effect of salivary pellicle in preventing dental erosion.(7,19) Therefore, this concise review aimed to provide an overview on factors influencing the protective effect of salivary pellicle against dental erosion.

Protective effect of salivary pellicle in the literature

The literature search of this concise review was conducted on three databases, EMBASE, PubMed, and Scopus, to recruit articles published between 1 January 2000 and 30 September 2024. The keywords used in the search were (“Salivary pellicle” OR “Acquired salivary pellicle” OR “Acquired enamel pellicle” OR “Acquired dentin pellicle”) AND “Protection” OR “Protective effect*” OR “Anti-erosion” OR “Anti-erosive”) AND (“Tooth erosion” OR “Dental erosion” OR “Eroded” OR “Erosive lesion” OR “Erosive tooth wear”). The inclusion criteria were (i) studies that assessed the protective effects of salivary pellicle and (ii) studies published between 1 January 2000 and 30 September 2024. The exclusion criteria were (i) studies on another type of tooth loss such as attrition, abrasion, and abfraction, (ii) studies of the protective effects of a salivary pellicle in animal study, (iii) studies on the anti-erosive effect of topical anti-erosive agents, (iv) studies on mucosal pellicle or whole saliva or dental plaque, (v) studies on restorative materials, and (vi) studies published in not English language. Figure 1 shows a flowchart of our systemic search of this concise review.

Factors influencing the protective effect of salivary pellicle against dental erosion

Intraoral location of salivary pellicle

The intraoral location of the salivary pellicle relates to the salivary gland.(20-22) Different salivary glands influence the composition, thickness, and protective effect of the salivary pellicle. Parotid salivary glands mainly secrete amylase and proline-rich proteins (PRPs).(20) It produces serous saliva, which contains more fluid composed of water and proteins.(23) The serous saliva has a high

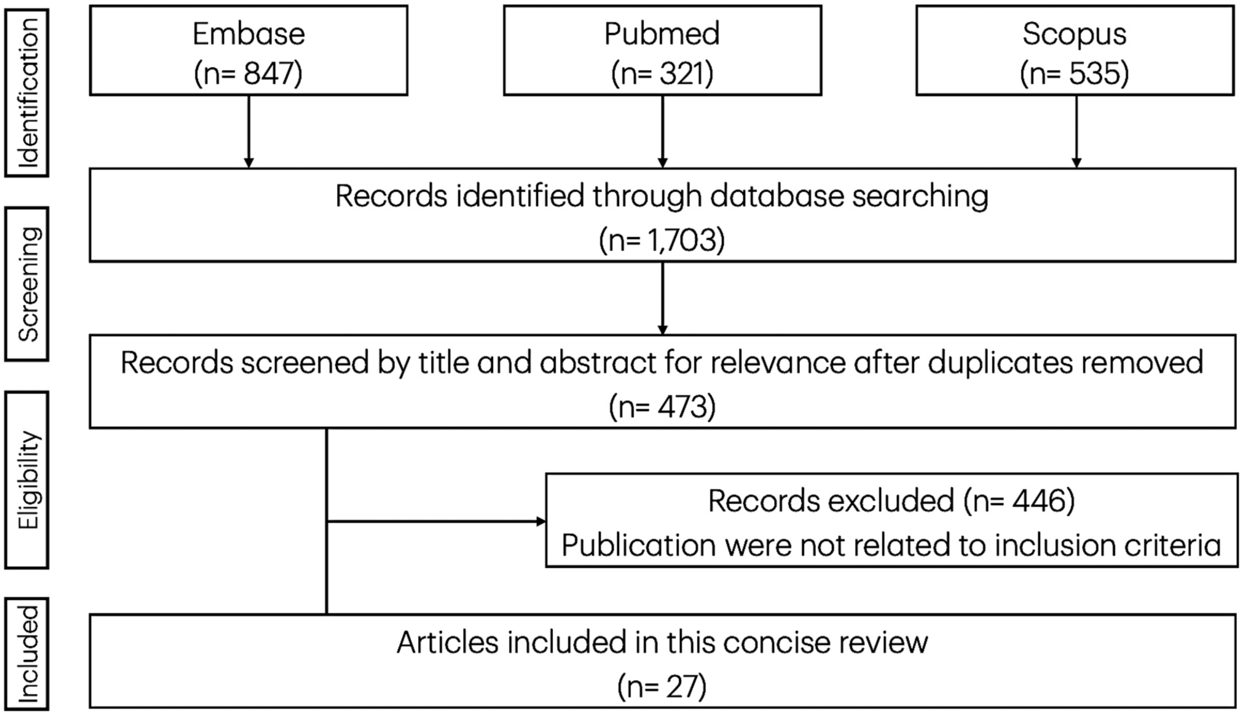

Figure 1: Flowchart summarizing the reference selection process.

buffering capacity.(23) Meanwhile, sublingual salivary glands mainly secrete mucins and lysozymes.(20) It produces mucous saliva, which contains high glycoprotein mucin.(23) The mucous saliva has a high flow rate and low buffering capacity.(23) Therefore, salivary pellicle derived from mucous saliva is easy to dissolve and has less protective effect.(20,23) In addition, the occlusal surface of posterior teeth and the incisal edge of anterior teeth are covered by salivary pellicle originating from mucous saliva.(23) Consequently, these surfaces have been reported as prone to dental erosion.(23) Moreover, the salivary pellicle at the area of mixed sublingual and submandibular salivary glands has a high level of mucins.(24) It can provide high protective effect against dental erosion.(24) It should be noted that the protective effect of intraoral location of salivary pellicle in previous studies was inconsistent and inconclusive, depending on the study design and methodology.(20,23,25)

Tooth substrate

Some studies reported that salivary enamel pellicle provided a superior protective effect than the salivary dentine pellicle.(12,22,26) Moreover, the salivary enamel pellicle exhibited a twofold protective effect compared to the salivary dentine pellicle.(26) It would be that during salivary dentine pellicle formation, adsorbed salivary proteins attach to either the dentine surface or dentinal tubule.(27) Dentinal tubular fluids may interfere with the formation of the salivary dentine pellicle.(27) Furthermore, numerous enzymes within the dentine structure, including matrix metalloproteinases and other proteolytic enzymes, can be released into the surrounding area following erosive acids attack.(12) These enzymes cause proteolytic activity of the adsorbed salivary proteins, potentially resulting in the dislodgment of the salivary pellicle.(12)

Thickness of salivary pellicle

The intraoral location of the salivary pellicle and type of salivary glands in the oral cavity influence its thickness.(12,27) The thickness of the salivary pellicle on the buccal site at the maturation stage is thicker than the palatal site.(6) Salivary pellicle near salivary duct openings is thinner.(27) The salivary pellicle on the lingual surface of the lower teeth is the thickest.(12) On the contrary, the salivary pellicle on the palatal surface of the upper teeth is the thinnest.(12) Furthermore, at the same intraoral location, the thicker salivary pellicle has a greater protective effect against dental erosion than the thinner salivary pellicle.(15)

Formation time of salivary pellicle

It takes 60-120 minutes for the salivary pellicle to reach the maturation stage of formation time.[6,12] Many *in situ* studies have investigated the protective effect of different formation times of salivary pellicle.[1,6,20,28] The results showed no significant differences in the protective effect of salivary pellicle with the formation time of 3 minutes, 30 minutes, 1 hour, and 2 hours.[1,6,20,28] Remarkably, even a salivary pellicle that formed in just 3 minutes was effective in protecting the tooth from dental erosion.[1] Nevertheless, another study showed that the salivary pellicle formed at a short-term was more soluble and rapidly dissolved during acidic demineralization.[14] Consequently, the salivary pellicle formed in 2 hours, effectively supported its maximum anti-erosive properties.[1,7] Notably, previous studies showed inconsistent results of the protective effect of various formation times of salivary pellicle.[6,12,14,25] Hence, further study is required to confirm its thickness and the protective effect of the salivary pellicle.

Composition of salivary pellicle

Adsorbed salivary proteins are a critical factor in the protective effect of the salivary pellicle.[22,29] Previous studies reported that the composition of salivary pellicle in dental erosion patients differed significantly from healthy volunteers.[11,15] The level of total proteins, statherin, and calcium-binding proteins in the salivary pellicle of dental erosion patients was reduced.[11,30] These proteins are acid-resistant proteins, maintain calcium and phosphate ions on the tooth surface, and have a strong adsorption capability to hydroxyapatite of tooth structure.[1,16] Hence, the salivary pellicle from dental erosion patients had a less protective effect than normal salivary pellicle from healthy volunteers.[11,15,30] However, the levels of mucins, albumin, and carbonic anhydrase were not significantly different in dental erosion patients and healthy volunteers.[4,11,15] In addition, lipids components such as phospholipids and fatty acids influence the composition and ultrastructure of salivary pellicle.[30,31] It also has an important role in the bioadhesion processes on the tooth surface.[31] Although phospholipids and fatty acids can modify the salivary pellicle, the study of lipids on the protective effect of the salivary pellicle is still limited.[31]

pH level of erosive acids

Erosive acids can demolish the outer layers of salivary pellicle during erosive challenge.[18] Consequently, the protective effect of salivary pellicle can significantly decrease with the increased acidity of acids.[18] The severity of salivary pellicle destruction depends on the pH level of erosive acids.[17,18] The pH of common commercial acidic beverages is approximately 2-3.[2] Carbonated drinks have a lower pH than fruit juices.[32] Carbonated drinks have tenfold more erosive potential than fruit juices.[17,32] Therefore, it can reduce salivary pellicle by half compare to fruit juices.[17] Notably, a low pH level of the acids with prolonged exposure time would synergistically diminish the protective effect of the salivary pellicle.[33]

The exposure time to erosive acids

Salivary pellicle counteracts erosive acids at the first second of exposure.[17] During the erosive challenge, the binding forces between the tooth surface and the salivary pellicle layer are decreased.[28,34] Adsorbed proteins of the salivary pellicle are detached, and the salivary pellicle is partially dislodged.[28,34] In addition, prolonged exposure time to erosive challenge can delay the re-organization and repair phases of the salivary pellicle.[28,34] Ultimately, prolonged exposure time results in a loss of structure and protective effect of the salivary pellicle.[18,34]

Modification of salivary pellicle against dental erosion

Modification of the salivary pellicle is an important concept to improve the protective effect of the salivary pellicle by altering the ultrastructure of the pellicle[35,36], modifying the composition of the pellicle[24], and promoting rehardening of the softened tooth surface by providing mineral contents from salivary pellicle.[37] To date, nutritional components such as casein in milk, polyphenolic compounds, lipophilic agents, fluoride, albumin, and xanthan gum have been investigated to modify salivary pellicle.

In preventive dentistry, modifying salivary pellicle could be developed to prevent and manage dental erosion.[19] Fluoride is the most common agent that has been investigated for modifying salivary pellicle against dental erosion.[19] Sodium fluoride, stannous fluoride, amine fluoride, and silver diamine fluoride had a positively synergistic effect with salivary pellicle against dental erosion.[14,36,38,39] It could be explained that fluoride can be incorporated with the adsorbed salivary proteins during salivary pellicle formation.[36] After that, the composition of salivary pellicle may change properties to obtain more acid resistance.[40] The fluoride may facilitate the adsorption of adsorbed salivary proteins such as mucins and albumin on the tooth surface.[41,42] Furthermore, fluoride can increase the thickness of salivary pellicle on the surface.[36,40] Therefore, fluoride is a promising agent that enhances the protective effect of the salivary pellicle against dental erosion.

Conclusions

Salivary pellicle is a thin layer that covers all tooth surfaces. The salivary pellicle serves as a physical barrier to impede direct contact between erosive acids and the tooth surface. It is a semipermeable membrane that facilitates mineral ions diffusion. In addition, adsorbed salivary proteins, such as mucins, statherin, and PRPs in the salivary pellicle, contribute to its buffering capacity. The protective effect of salivary pellicle depends on two factors: 1) characteristics of the salivary pellicle, such as intraoral location, tooth substrate, thickness, formation time, and composition and 2) characteristics of erosive acids, such as pH level and exposure time. Therefore, these factors should be considered to enhance the protective effect of the salivary pellicle in preventing dental erosion. Future research should further investigate these factors to optimize the therapeutic applications of salivary pellicle in dental care.

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Original Article

Self-etching Ceramic Primer Protocol Provides Efficient Shear Bond Strength and Durability Between Lithium Disilicate Glass-ceramic and Resin Cement: A Potential Alternative to the Conventional Hydrofluoric Acid Protocal

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Abstract

Objectives: This study investigated the effects of two surface treatment protocols on the shear bond strength, bond durability, and failure mode at the interface between lithium disilicate glass-ceramic and resin cement. The protocols compared were a self-etching ceramic primer and the conventional hydrofluoric acid (HF) etching followed by silane.

Methods: Fifty lithium disilicate specimens were randomly divided into five surface treatment groups (n=10 each). A control group received no treatment. The remaining 4 groups included: 5% HF etch with Monobond Plus thermocycled and non-thermocycled, Monobond Etch & Prime (MEP), thermocycled and non-thermocycled. Microshear bond strength (microSBS) was assessed before and after thermocycling to evaluate bond durability. Failure modes (adhesive, mixed, cohesive in resin/ceramic) were recorded under a stereomicroscope.

Results: Both surface treatment protocols exhibited comparable microSBS for both pre- and post-thermocycling results. Moreover, bone durability obtained from the two treatment protocols seemed to be comparable. Most groups displayed adhesive/mixed failures. Notably, the self-etching ceramic primer group showed cohesive failure in half of the specimens initially, persisting in 20% after thermal aging.

Conclusions: Compared with the conventional HF protocol, the self-etching ceramic primer protocol provided similar microSBS and bond durability between lithium disilicate glass-ceramic and resin cement. The data suggest a self-etching ceramic primer is a viable option for the conventional HF protocol in bonding to glass-ceramic, minimizing the HF hazard and simplifying the clinical procedure.

Keywords: bond durability, bond strength, hydrofluoric acid, lithium disilicate, self-etching ceramic primer

Introduction

Current protocols for glass-ceramic surface treatment typically involve hydrofluoric acid (HF) etching followed by silane application. This multi-step process enhances bonding through a combination of chemical and micromechanical mechanisms. HF etching roughens the ceramic surface, increasing its surface area for mechanical interlocking with resin cements, and it also promotes the formation of hydroxyl groups on the ceramic surface, facilitating a chemical bond with silane coupling agents.(1) Silane molecules possess a bifunctional structure, with one end capable of covalently bonding to the hydroxyl groups on the ceramic and the other end designed to interact with the resin cement, effectively creating a chemical bridge at the interface.(2) Numerous studies have demonstrated the synergistic effect of this combined approach, with HF etching followed by silane application consistently yielding optimal bond strengths between ceramic and resin cements.(3,4)

HF etching is a process known to be hazardous due to its potential for oral mucosa and cutaneous burns.(5) Prolonged etching time with hydrofluoric acid could jeopardize the flexural strength of the restorative material.(6,7) To address these safety concerns, self-etching ceramic primers have been introduced as possible alternatives.(4) The composition of one currently available commercial self-etching ceramic primer product contains ammonium polyfluoride, which reacts with ceramic surface to create a rough etching pattern, and also contains trimethoxypropylmethacrylate -functionalized silane, according to the manufacturer's specifications.(8) A self-etching ceramic primer chemically modifies the ceramic surface to enhance bonding, eliminating the need for separate HF etching and silanization steps.(4,8) This approach not only improves safety but also reduces treatment time and potentially reduces patient discomfort during the bonding procedure. However, studies have yielded mixed results regarding the bond strength achieved with silane-containing self-etching primers compared to conventional HF-etching and silanization. Some investigations report comparable bond strengths(9-11), while others observe a slight decrease(3) or a statistically significant reduction.(12-15) Therefore, this *in vitro* study investigated the effects of two surface treatment. protocols on the microshear bond strength and durability of resin cement to lithium disilicate glass-ceramics. The protocols compared were: (1) conventional HF etching followed by silane application protocol and (2) self-etching ceramic primer application protocol. Thermal aging simulation was used to determine their bond durability. The null hypothesis postulated no significant differences in microshear bond strength and durability between the two surface treatment protocols for bonding resin cement to lithium disilicate glass-ceramics.

Materials and Methods

Specimen preparation

A total of four CAD/CAM blocks (12×14×18 mm) of lithium disilicate glass ceramic (IPS E.max® CAD; Ivoclar Vivadent, Schaan, Liechtenstein) were used in this study. The blocks were cut into 50 rectangular sections (12×7×2 mm) using a diamond wheel saw (Accutom-50, Struers) under water irrigation. Afterwards, the ceramic specimens were fired according to the crystallization program (P161 Crystallization LT/MT/HT) in a furnace (Programmat P310, Ivoclar Vivadent) as recommended by the manufacturer. After cooling, the specimens were cleaned ultrasonically and mounted on polyvinyl chloride (PVC) rings filled with acrylic resin, displaying the specimen surface on the top of the cylinder, with a height of 1 mm. The mounted specimens were cleaned ultrasonically in isopropyl alcohol for 60 seconds.

Surface treatment & storage conditions

The specimens were randomly assigned into 5 groups, each consisting of 10 specimens based on surface treatment and storage conditions. Material compositions are shown in Table 1. The five surface treatment groups were listed as follows:

Group 1. Control: no treatment (NT)

Group 2. Conventional HF & silane protocol: etched with <5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 20 seconds, thoroughly rinsed with water spray until the red color was removed, dried with oil-free air for 20 seconds, followed by the application of Monobond Plus for 60 seconds using a microbrush, and dispersed remaining excess with oil-free air for 10 seconds, specimens were stored in distilled water at 37°C for 24 hours

Group 3. Conventional HF & silane protocol +TC: same as Group 2 but stored under thermal cycling conditions, cycled between 5°C and 55°C for 10,000 cycles with 5-second dwell times

Group 4. Self-etching ceramic primer protocol: treated with self-etching ceramic primer (Monobond Etch & Prime, MEP; Ivoclar Vivadent) by agitating onto the ceramic surface for 20 seconds using a microbrush, left the agent for another 40 seconds to react, thoroughly rinsed with water spray until the green color was removed, and dried with oil-free air for 10 seconds, specimens were stored in distilled water at 37°C for 24 hours

Group 5. Self-etching ceramic primer protocol +TC: same as Group 4 but stored under thermal cycling conditions, cycled between 5°C and 55°C for 10,000 cycles with 5-second dwell times.

Resin cement application

After the surface treatment (NT, HF, or MEP), Tygon® tubes with an internal diameter of 0.8 mm and a height of 1 mm were positioned over the ceramic surface using perforated adhesive tape as a stabilizer to prevent movement during resin cement application. One operator positioned two tubes on each ceramic surface followed by the application of resin cement (Multilink N, Ivoclar Vivadent, Schaan, Liechtenstein). The resin cements were light-cured for 40 seconds using a LED light-curing unit with an output of 1,200 mW/cm². After each mode of storage, the tubes were carefully removed with a sharp scalpel blade. Each specimen was examined for any defects in the resin cylinders, and no porosities or gaps at the interface were observed. The procedures were carried out under 3.5X magnifying loupes.

Microhear bond strength test

The PVC rings were mounted in a universal testing machine (EZ-test-50N, Shimadzu Co, Japan). The shear blade was positioned close to the resin cylinder and the load was applied at a constant crosshead speed of 1 mm/minute until failure occurred. The microSBS values (MPa) were calculated by dividing the load at failure by the surface area (mm²).

Failure mode analysis

After the microSBS test, the ceramic surfaces of all debonded specimens were examined under a stereomicroscope (SMZ1000, Nikon, Japan) at x40 magnification to determine the failure modes. Failure modes were classified into four types: adhesive failure (AD), characterized by separation at the interface between the resin cement and ceramic; mixed failure (M), combining a combination of adhesive and cohesive failure; cohesive failure within the resin cement (CR); and cohesive failure in ceramic (CC).

Table 1: The products used in this study.

Product	Composition	Manufacturer
1. Ceramic		
IPS e.max CAD	SiO2, Li2O, K2O, MgO, ZnO2, Al2O3, P2O5 and other oxides	Ivoclar Vivadent, Schaan, Liechtenstein
2. Etchant		
IPS Ceramic Etching Gel	4.9% HF acid, water, colorant (pH=2)	Ivoclar Vivadent, Schaan, Liechtenstein
3. Silane		
Monobond Plus	Silane methacrylate, phosphoric acid methacrylate, sulphide methacrylate, ethanol	Ivoclar Vivadent, Schaan, Liechtenstein
4. Self-etching ceramic primer		
Monobond Etch and Prime (MEP)	TADF, silane methacrylate, BTSE, methacrylated phosphoric acid ester, butanol, water, colorant (pH=3.7)	Ivoclar Vivadent, Schaan, Liechtenstein
5. Resin cement		
Multilink N	Monomer matrix: HEMA, Dimethacrylate Inorganic fillers: 0.25–3.0 µm of barium glass, ytterbium trifluoride, spheroid mixed oxide	Ivoclar Vivadent, Schaan, Liechtenstein

** According to the manufacturers' information. TADF: Tetrabutyl ammonium dihydrogen trifluoride, BTSE: Bis(triethoxysilyl)ethane, HEMA: 2-Hydroxyethyl Methacrylate.*

Statistical analyses

The microSBS values were expressed as the mean ± standard deviation (SD) (N=10 per group). Inter-group comparisons of microSBS were performed using a one-way analysis of variance (ANOVA) with Tukey's post hoc comparison. Failure modes were analyzed descriptively, with percentages used to quantify their prevalence. Fisher's exact test has been used to find an association between type of primer type and failure mode. A significance level of α=0.05 was employed. Statistical analyses were conducted using the statistical software package SPSS version 28.0 (SPSS Inc.).

Results

Mean microSBS values are depicted in Table 2. For the control no surface treatment group, resin cements debonded in six specimens before the microSBS test. The mean microSBS was significantly lower than 1 MPa. After storage in distilled water at 37°C for 24 hours, both surface treatment protocols exhibited comparable initial non-aged microSBS (12.39 MPa for the conventional HF & silane group vs 11.92 MPa for the self-etching ceramic primer group). After 10,000 cycles of thermal aging, the microSBS values obtained from both protocols were still statistically similar (13.48 MPa for the conventional HF & silane group vs 10.36 MPa for the self-etching ceramic primer group). Considering the thermal aging process, no significant differences in microSBS were observed between the groups with and without TC within the same surface treatment protocol (Table 2).

There were 3 types of failure mode found as shown in Figure1. The frequency distribution of the resulting failure modes following microSBS testing is shown in Table 3. The control group, with no surface treatment, exhibited 100% adhesive failure. Adhesive or mixed modes of failure were common in all groups except for the self-etching ceramic protocol group. Half of the self-etching ceramic primer-treated specimens stored in distilled water at 37°C for 24 h exhibited cohesive failure in the resin cement, which was still observed in 20% of the specimens after thermal aging. Fisher's exact test revealed a correlation between types of failure mode and the groups tested.

Discussion

This study investigated the efficacy of a user-friendly and less hazardous self-etching ceramic primer for surface pretreatment of lithium disilicate, a commonly used glass-ceramic material. The aim was to compare its bonding effectiveness to the traditional HF etching method. The microSBS testing was employed to assess bonding performance. Results indicated that the self-etching ceramic primer protocol achieved microSBS values, both

Table 2: Mean microSBS values (MPa) of the five experimental groups.

Experimental groups	microSBS (mean ± SD)
1. Control (untreated surface)	0.96±1.02^{A}
2. Conventional HF & silane protocol	12.39±5.55^{B}
3. Conventional HF & silane protocol + TC	13.48±5.18^{B}
4. Self-etching ceramic primer protocol	11.92±5.17^{B}
5. Self-etching ceramic primer protocol + TC	10.36±3.6^{B}

Different superscript letters indicate statistically significant difference. TC: thermocycling.

Table 3: Frequency distribution of failure modes (%) of the five experimental groups.

Experimental groups	Failure modes (%)			
	AD	M	CR	CC
1. Control (untreated surface)	100	0	0	0
2. Conventional HF & silane protocol	20	70	10	0
3. Conventional HF & silane protocol + TC	70	30	0	0
4. Self-etching ceramic primer protocol	40	10	50	0
5. Self-etching ceramic primer protocol + TC	40	40	20	0

AD, adhesive failure; M, mixed failure; CR, cohesive failure in resin cement; CC, cohesive failure in ceramic.

initial and aged, comparable to the conventional HF and silane protocol for bonding to lithium disilicate glass-ceramic. Consequently, the null hypothesis, which posited that the self-etching primer would provide microSBS and bond durability similar to the recommended HF and silane protocol, cannot be rejected.

Established literature demonstrates a positive correlation between adhesion and the reinforcement of esthetic indirect restorations achieved through adhesive techniques. Conversely, insufficient bonding between the restoration and resin cement may lead to an uneven distribution of stresses. This non-uniform stress distribution can culminate in the resin cement layer and weaken the unsupported restoration under occlusal forces, ultimately leading to restoration failure.(4) Although HF etching followed by silane application has long been used with great success for bonding to glass-ceramic substrates, this surface treatment protocol using HF, which is highly hazardous and toxic(5), did not provide significantly higher bond performance, at least in terms of microshear bond strength and durability, as demonstrated in the present study. The present results provide evidence supporting the potential clinical success of the self-etching ceramic primer comparable to the recommended HF-containing procedure, as previously reported.(9-11) According to the manufacturer's documentation(8), tensile bond strength, shear bond strength and aging resistance obtained from the application of self-etching ceramic primer are comparable to the conventional combination of hydrofluoric acid etching and Monobond Plus application but superior to other universal adhesives. From El-Damanhoury's study(3), the etching pattern created by self-etching ceramic primer had less surface roughness and a less dominant etching pattern compared to conventional hydrofluoric acid, while the surface morphology was more uniform. Despite this reduced roughness, it seems to be sufficient for retention, and the ceramic surface does not become over-etched after prolonged exposure. Several studies(3,4), evaluate the effect of self-etching ceramic primer at different durations (60, 100 and 140 seconds). The result shown that there were no significant changes on surface morphology on glass ceramic and no impact on shear bond strength. Evaluating the impact of thermal aging, no statistically significant differences in microSBS bond strengths were observed between groups with and without thermocycling within the same surface treatment protocol. This finding suggests that both surface treatment protocols achieve comparable bond durability following *in vitro* simulation of thermal aging. These encouraging results justify further clinical investigations to confirm the clinical relevance of the self-etching ceramic primer.

Although HF reacts with the matrix, such as glass-ceramics, that contains the silica, generating a micro-mechanically retentive surface and promoting hydroxyl group formation on the ceramic surface for enhanced bonding(16), well-controlled HF etching technique is crucial to achieving optimal bonding performance. Previous studies suggested that prolonged HF etching times negatively affect the flexural strength of the materials(6,7) and that neither an increase in etching time nor concentration resulted in a statistically significant enhancement of bond strength.(17) The observed similarity in bond performance between the traditional HF-etching protocol and the single-step self-etching ceramic primer protocol, despite the latter's less technique-sensitive nature, may be attributed to the technique sensitivity of the former. Moreover, thermocycling conditions may play an important role in the bond performance obtained from a previous study(3) that reported conflicting results with the present study. That study employed long dwell times of about 30 seconds in each temperature, while the present study used only 5-second dwell times in each temperature, which has been

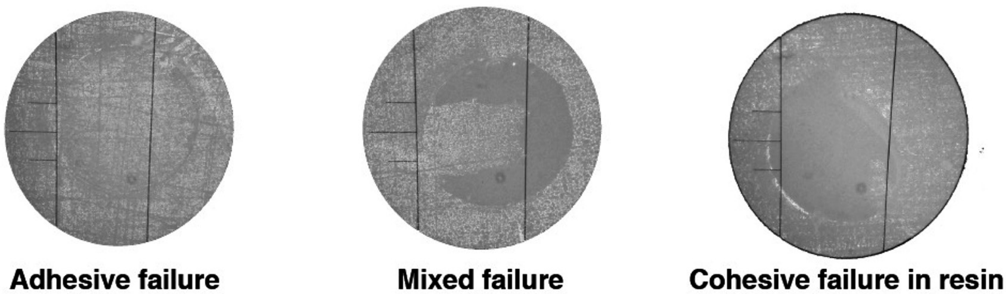

Figure 1: Representative sterio microscopic images of three fracture modes: adhesive failure (AD), mixed failure (M) and cohesive failure within the resin cement (CR).

proposed to simulate more accurately the actual changes of temperature occurring in the oral cavity since no patients would be able to tolerate an extreme temperature for an extended period of time.[18,19] The number 10,000 cycle can represent approximately one year of intraoral aging.[19] This could provide us with more information on the long term performance of self-etching ceramic primers. Future investigation into the underlying bond mechanisms of both protocols would undoubtedly shed light on achieving strong and durable resin-ceramic bonds.

Interestingly, the self-etching ceramic primer protocol exhibited a lower incidence of adhesive failure compared to the conventional HF & silane protocol. This observation held true for both freshly prepared and aged specimens. These failure pattern results obtained from both initial and thermally aged specimens suggest that the self-etching ceramic primer-treated surface provides a strong and durable resin-ceramic bond. Further studies focusing on the analysis of failure patterns obtained in the present study are important to gain insights into the potential success or failure of this alternative surface treatment approach in clinical settings. Although a cohesive failure within resin cement generally signifies that the resin cement's adhesion to the ceramic surpasses the resin cement's cohesive shear strength, further investigations are warranted to elucidate the mechanisms underlying the observations presented in this study.

The limitations of this study included the use of only one type of artificial aging and ceramic material. Future research should incorperate additional types of artificial aging, beyond thermal cycling, and conduct more clinical study to evaluate the long-term performance of this seft-etching ceramic primer protocal.

Conclusions

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

1. For bonding to lithium disilicate glass-ceramic, the self-etching ceramic primer protocol performed similarly to the HF & silane conventional protocol in terms of initial and aged microSBS.

2. Thermal aging did not affect microSBS obtained from both self-etching ceramic primer and HF & silane conventional protocols.

3. Compared to the conventional HF & silane protocol, the self-etching ceramic primer protocol resulted in lower prevalence of adhesive failure for both initial and aged specimens after thermal aging.

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Conflicts of Interest

The authors declare no conflict of interest.

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The Comparison of The Quality of Life Between Conventional Orthognathic Surgery and Surgery-first Orthognathic Surgery in Skeletal Class III Deformity Patients

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Abstract

Objectives: This prospective cohort study aimed to compare the quality of life (QoL) of patients with skeletal Class III deformities undergoing either conventional orthognathic surgery (CS) or surgery-first orthognathic surgery (SF) using the Orthognathic Quality of Life Questionnaire (OQLQ) and the Oral health Impact (OHIP-14) tools.

Methods: The OQLQ was translated into Thai. Thirty-four patients were enrolled, with 17 in each group according to their orthodontic treatment plans. Patients completed the OQLQ and OHIP-14 assessments on the day before surgery (T1) and at 1 month (T2), 3 months (T3), and 6 months (T4) post-surgery. Data collection occurred from October 2021 to April 2022. Independent sample T-tests and one-way repeated measures ANOVA were used for statistical analysis ($p<0.05$).

Results: At T1, the QoL was significantly lower in the CS group compared to the SF group. The CS group exhibited significant QoL improvements at T2 (OQLQ) and T3 (OHIP-14) compared to T1. The SF group had a lower QoL at T2 but showed significant improvement at T4 (OQLQ and OHIP-14).

Conclusions: There was no significant difference in QoL between the two groups after surgery. Both surgical approaches led to improvements in patients' QoL. Thus, the choice of surgical method should be based on appropriate indications and patient-doctor agreement.

Keywords: conventional orthognathic surgery, OHIP-14, OQLQ, quality of life, surgery-first orthognathic surgery

Introduction

Skeletal deformity is defined as deformities caused by the malformed anatomy of the jawbones, midface, and lower face, together with irregular tooth position.[1] Individuals with skeletal deformities often encounter difficulties in social interaction, affecting their self-confidence, societal acceptance, and overall quality of life (QoL), which are significant factors motivating patients to decide to undergo orthodontic treatment with orthognathic surgery.[2,3]

In conventional orthognathic surgery, there is a pre-surgical orthodontic treatment phase, which worsens facial abnormalities and reduces chewing efficiency.[4-6] The pre-surgical orthodontic phase normally takes 12-24 months.[5,7,8] The emergence of the surgery-first approach (SFA) in orthognathic surgery aims to shorten or eliminate the pre-surgical orthodontic phase, providing patients with immediate post-surgical facial changes, consequently reducing the overall treatment duration.[5,7,8]

To evaluate the QoL of patients with oral health problems, many tools have been developed, such as the Orthognathic Quality of Life Questionnaire (OQLQ)[9] and the Oral Health Impact Profile-14 (OHIP-14).[10] The OQLQ is specifically used to investigate the impact of orthognathic surgery on the patients' QoL and comprises 22 items from four domains: facial esthetics, oral function, awareness of facial deformities, and social aspects of deformity. The total score of the OQLQ is from 0 to 88 points. The OHIP-14 is a global oral health assessment instrument that assesses patients' oral health-related QoL, which comprises 14 questions from seven domains, including functional limitation, physical pain, psychological discomfort, physical disability, psychological disability, social disability, and handicap. The total score of the OHIP-14 is from 0 to 56. Higher scores on both tools indicate a greater impact on the patient's QoL.

There have been several studies comparing the QoL between patients undergoing conventional orthognathic surgery and surgery-first orthognathic surgery. Huang *et al.*,[6] conducted a study on 50 patients with class III dentofacial deformity who underwent bilateral sagittal split osteotomy (BSSRO), divided into 25 patients in each group. This study used the Dental Impact on Daily Living (DILD) and the OHIP-14 before surgery and at 1, 6, 12, and 18 months after the start of orthodontic treatment, and at the end of orthodontic treatment. The surgery-first group had better QoL than the conventional group at all time intervals, but the difference was not statistically significant. Park *et al.*,[11] studied 26 class III patients, divided into conventional group (N=15) and surgery-first (N=11) groups. Patients retrospectively rated the OQLQ at initial presentation, just before surgery, 3 months after surgery, and at debonding. There were no significant differences in each domain and at each stage between the two groups. Pelo *et al.*,[12] used both the OHIP-14 and OQLQ. The subjects consisted of 30 patients with class II and class III dentofacial deformity who underwent two-jaw surgery. Each group included 15 patients. The questionnaires were completed before bracket placement, 1 month before surgery, and 1 month after surgery. There was no significant difference in the QoL between the two groups at 1 month after surgery. Saghafi *et al.*,[13] studied 32 patients who underwent orthognathic surgery, divided into two groups (surgery-first: N=18, orthodontic-first group: N=14). This study assessed the QoL using the OQLQ, the Generalized Anxiety Disorder (GAD-7) questionnaire, and the Patient Health Questionnaire (PHQ-9) at 1 week preoperatively, and 6 weeks and 6 months postoperatively. QoL was significantly better in the surgery-first group preoperatively. Both approaches resulted in an improvement in the QoL at 6 weeks postoperatively. A variety of assessment tools were used to evaluate the QoL across different phases of treatment in systematic reviews by Zamboni *et al.*,[14] and Cremona *et al.*,[15] including the OQLQ, OHIP-14, and the Short Form Health Survey (SF-36). The results indicated high rates of patient satisfaction and improved oral health-related QoL following orthognathic surgery. A systematic review and meta-analysis by Zheng *et al.*,[16] explored the effects of the surgery-first approach(SFA) on QoL and mental health of patients compared to the conventional three-stage approach (CTA). Eight studies were included, using the OHIP-14, OQLQ, the Psychosocial Impact of Dental Aesthetics Questionnaire (PIDAQ) and the Beck Depression Inventory (BDI-II) to examine QoL and mental health. This study found that orthognathic treatment with SFA can immediately enhance the QoL at the end of the first-stage treatment. In terms of overall treatment, both SFA and CTA have similar effects on the QoL.

This study was initiated due to an increasing number of patients undergoing surgery-first orthognathic surgery at the Faculty of Dentistry, Chiang Mai University, Thailand. The QoL of the patient is an important factor to consider when providing treatment. The study was performed in skeletal class III deformity patients undergoing orthognathic surgery. The primary outcome of this study was to compare the QoL between patients undergoing conventional orthognathic surgery and surgery-first orthognathic surgery using the OQLQ and OHIP-14.

Materials and Methods

This prospective cohort study compared the QoL of individuals with skeletal class III deformities who had orthognathic surgery at the Oral and Maxillofacial Surgery Clinic, Faculty of Dentistry, Chiang Mai University, Thailand, from October 2021 to April 2022. The study received ethical approval from the Human Experimental Committee of the Faculty of Dentistry, Chiang Mai University, Thailand (No.47/2021). Prior to participation, patients provided informed consent for the release of their responses to the questionnaires to the researchers.

Participants

The sample size was calculated using Gpower version 3.1 software, with reference to the study by Pelo *et al.*,[12] The calculation showed that 32 samples were needed. The total sample size increased from 32 to 34, accounting for a 5% drop out rate. The 34 participants were separated into two groups based on the treatment plan agreed upon between the patient and the orthodontist. The first group consisted of 17 patients who underwent conventional orthognathic surgery (CS) group to serve as the control. The other group included 17 participants who underwent surgery-first orthognathic surgery (SF) group and served as the experimental group.

The inclusion criteria were patients with a skeletal Class III facial appearance, an ANB value of less than 0.5 on a lateral cephalometric radiograph, and a normal SN value.[17] The patients had an orthodontic treatment plan involving either CS or SF orthognathic surgery.

The exclusion criteria included the following: patients with skeletal class III deformity who were undergoing camouflage orthodontic treatment; patients with other abnormalities of the jaw and face, such as cleft lip and/or cleft palate or craniofacial anomalies; patients who had previously undergone orthognathic surgery; patients with psychological disorders; patients who could not read and understand the Thai language; patients who were unable to comply with postoperative treatment follow-up for 6 months; patients with a history of maxillofacial trauma; and patients who had undergone cosmetic surgery including injectable filler that may affect facial contours.

Orthognathic quality of life questionnaire translation and validation

The Orthognathic Quality of Life Questionnaire (OQLQ) was translated from English to Thai following the cross-cultural translation process outlined by Beaton *et al.*[18] The steps involved initial translation, synthesis of translations, and back translation from Thai to English. Subsequently, the expert committee review process involved comparing the original version with the back-translated version. After all questions were revised, the Thai version of the OQLQ was obtained. Then, the reliability of the Thai version of the OQLQ was assessed by administering it to a group of 30 patients who had undergone orthognathic surgery for at least one year. The scores were analyzed to determine the questionnaire's reliability using Cronbach's α-coefficient computed through SPSS software. The Cronbach's α-coefficient of this questionnaire is 0.913, exceeding the minimum acceptable value of 0.70.[19]

Questionnaire administration

All participants in both the CS group and the SF group were asked to complete QoL assessments using the Thai version of the OQLQ and the Thai version of OHIP-14.[10] Participants were asked to read and complete the questionnaires one day before the surgery, marked as the preoperative period (T1), and during follow-up periods at 1 month (T2), 3 months (T3), and 6 months (T4) after surgery.

Normality and homogeneity tests were performed using the Shapiro–Wilk test and Levene's test, respectively. The independent sample t-test was used to evaluate the QoL scores between the 2 groups at T1, T2, T3, and T4, with a 95% confidence level ($p<0.05$). One-way repeated

Table 1: Demographic findings. Statistical analysis by the Chi-square test.

	Conventional group	Surgery-first group	*p*-value
Gender			
Female (%)	12 (70.59)	12 (70.59)	1.000
Male (%)	5 (29.41)	5 (29.41)	
Age (years)			
Range	20 to 34	17 to 54	0.900
Mean±SD	25.35±7.93	25.70±10.64	
Type of surgery			
Le Fort I osteotomy and BSSRO (%)	5 (29.41)	7 (41.18)	0.714
BSSRO (%)	12 (70.59)	10 (58.82)	
ANB (°)			
Range	-8 to -0.6	-8 to -0.8	0.975
Mean±SD	-4.18±2.43	-4.2±1.98	

BSSRO refers to bilateral sagittal split osteotomy.

measures ANOVA was used to assess the QoL scores for each group at different treatment intervals, with a 95% confidence level ($p<0.05$).

Results

The demographic data for the study participants are presented in Table 1. There were no significant differences between two groups.

Comparison of quality of life between conventional and surgery-first orthognathic surgery groups

There were statistically significant differences in the awareness and social domains and the total scores of the OQLQ between the CS and SF groups at T1. Postoperatively, statistically significant differences were observed in the domain of function at T2 and T3, as shown in Table 2. Table 3 shows statistically significant differences in all domains and total scores of OHIP-14 between the two groups at T1.

Comparison of the quality of life of patients undergoing orthognathic surgery at various intervals using the Orthognathic Quality of Life Questionnaire (OQLQ)

A comparison of the two groups' overall OQLQ scores is displayed in Figure 1. Patients in the CS group experienced noticeable enhancements in their QoL beginning at 1 month after surgery (T2). There were statistically significant ($p<0.05$) differences at T2, T3, and T4 compared to T1. In the SF group, a worse QoL was observed at T2, followed by improvements at T3 and T4. Significant changes ($p<0.05$) were seen at T2 and T4 compared to T1.

Comparison of the quality of life of patients undergoing orthognathic surgery at each interval using the Oral Health Impact Profile (OHIP-14)

The overall average OHIP-14 scores in the CS group showed a statistically significant ($p<0.05$) improvement in QoL at T3 and T4 compared with T1 (Figure 2). In the SF group, there was a decrease in QoL at T2 ($p<0.05$), followed by an improvement at T3 and T4 ($p<0.05$) compared to T1.

Discussion

Previous studies[20-27] that examined the QoL among patients with skeletal deformity undergoing orthognathic surgery primarily focused on those treated with CS. Several studies used only the OHIP-14[20-23] or the OQLQ[24-27] to assess QoL, depending on the objective of the assessment. The OHIP-14 is used to assess the impact of oral health on the QoL of patients in general across three dimensions (social, psychological, and physical) rather than focusing solely on effects attributable to specific oral disorders. OHIP-14 includes seven domains: functional limitation, physical pain, psychological discomfort, physical disability, psychological disability, social disability, and handicap domains. The OQLQ is specifically used to investigate the impact of orthognathic surgery on QoL and comprises four domains: facial esthetics, oral function, awareness of facial deformities, and social aspects of deformity. Here, however, we

Table 2: Comparison of the quality of life between patients treated with conventional orthognathic surgery (CS) and surgery-first orthognathic surgery (SF) during the preoperative period (T1) and at 1 (T2), 3 (T3), and 6 months after surgery (T4) using the Orthognathic Quality of Life questionnaire (OQLQ). Statistical analysis by independent sample t-test.

Domain		Pre-op (T1)		Effect size	*p*	1 month (T2)		Effect size	*p*	3 months (T3)		Effect size	*p*	6 months (T4)		Effect size	*p*
		CS	SF			CS	SF			CS	SF			CS	SF		
Aesthetic	Mean±SD	12.29±3.85	9.94±4.91	0.53	0.130	7.64±5.57	10.29±4.63	0.52	0.142	4.82±4.85	7.52±5.00	0.54	0.119	3.58±3.72	5.52±3.71	0.52	0.138
(0-20)	95% CI	10.46–14.12	7.60–12.27			4.99–10.28	8.08–12.49			2.51–7.12	5.14–9.89			1.81–5.34	3.75–7.28		
Awareness	Mean±SD	8.94±3.24	5.58±2.15	1.22	0.001**	7.94±2.96	7.23±2.90	0.24	0.489	5.00±3.04	5.82±3.28	0.25	0.454	4.70±3.61	5.05±3.52	0.09	0.775
(0-16)	95% CI	7.40–10.48	4.55–6.60			6.53–9.34	5.85–8.60			3.55–6.44	4.26–7.37			2.98–6.41	3.37–6.72		
Social	Mean±SD	15.70±6.08	8.94±4.58	1.25	0.001**	12.11±5.88	10.82±6.84	0.20	0.559	6.82±5.64	6.64±5.18	0.03	0.935	4.70±4.74	5.11±4.56	0.08	0.798
(0-32)	95% CI	12.81–18.59	6.76–11.11			9.31–14.90	7.56–14.07			4.13–9.50	4.17–9.10			2.44–6.95	2.94–7.27		
Function	Mean±SD	11.29±3.83	8.76±3.76	0.66	0.061	9.17±3.45	13.70±4.52	1.12	0.002**	6.29±2.99	9.23±3.73	0.86	0.016*	3.82±3.82	5.17±3.66	0.36	0.300
(0-20)	95% CI	9.46–13.11	6.97–10.54			1.66–5.23	11.55–15.84			4.86–7.71	7.45–11.00			2.00–5.63	3.43–6.91		
Total score	Mean±SD	48.23±12.34	33.23±10.32	1.31	0.001**	36.88±14.46	42.05±15.45	0.34	0.321	22.94±14.32	29.23±14.04	0.44	0.205	16.82±12.88	20.88±13.05	0.31	0.368
(0-88)	95% CI	42.36–54.09	28.32–38.13			30.00–43.75	34.70–49.39			16.13–29.74	22.55–35.90			10.69–22.94	14.67–27.08		

Table 3: Comparison of the quality of life between patients treated with conventional orthognathic surgery (CS) and surgery-first orthognathic surgery (SF) at the preoperative period (T1), 1 month (T2), 3 months (T3), and 6 months after surgery (T4) using the Oral Health Impact Profile (OHIP-14). Statistical analysis by independent sample t-test.

Domain		Pre-op (T1)		Effect size	*p*	1 month (T2)		Effect size	*p*	3 months (T3)		Effect size	*p*	6 months (T4)		Effect size	*p*
		CS	SF			CS	SF			CS	SF			CS	SF		
Functional limitation (0-8)	Mean±SD	2.88±1.49	1.64±1.27	0.89	0.014*	3.58±1.46	2.76±1.64	0.52	0.132	2.11±1.40	1.88±1.49	0.15	0.640	1.11±1.21	1.00±0.79	0.10	0.741
	95% CI	2.17–3.58	1.03–2.24			2.88–4.27	1.98–3.54			1.44–2.77	1.17–2.58			0.53–1.68	0.62–1.37		
Physical pain (0-8)	Mean±SD	4.05±1.369	2.52±0.87	1.31	0.001**	4.41±1.27	3.64±1.27	0.60	0.900	2.82±1.42	2.70±1.31	0.08	0.804	1.41±1.27	1.70±1.57	0.20	0.554
	95% CI	3.38–4.71	2.10–2.93			3.80–5.01	3.03–4.24			2.14–3.49	2.07–3.32			0.80–2.01	0.95–2.44		
Psychlogical discomfort (0-8)	Mean±SD	4.58±1.00	3.35±1.05	1.19	0.001**	3.41±1.62	3.41±1.27	0	1.000	2.35±1.80	2.70±1.72	0.19	0.563	1.47±1.77	1.88±1.40	0.25	0.459
	95% CI	4.10–5.05	2.85–3.84			2.64–4.18	2.80–4.01			1.49–3.20	1.88–3.51			0.62–2.31	1.21–2.54		
Physical disability (0-8)	Mean±SD	3.47±1.69	1.29±1.21	1.48	0.000**	3.35±1.27	2.64±1.76	0.46	0.190	2.00±1.32	1.52±1.46	0.34	0.333	1.29±1.49	0.58±0.87	0.58	0.101
	95% CI	2.66–4.27	0.71–1.86			2.74–3.95	1.80–3.47			1.37–2.62	0.82–2.21			0.58–1.99	0.16–0.99		
Psychological disability (0-8)	Mean±SD	4.00±1.11	2.29±1.21	1.47	0.000***	3.17±1.50	3.00±1.93	0.09	0.769	1.47±1.50	2.00±1.65	0.33	0.337	0.82±0.95	1.35±1.65	0.39	0.262
	95% CI	3.47–4.52	1.71–2.86			2.45–3.88	2.08–3.91			0.75–2.18	1.21–2.78			0.36–1.27	0.56–2.13		
Social disability (0-8)	Mean±SD	2.29±1.57	1.35±0.99	0.71	0.045*	2.05±1.14	2.00±1.36	0.03	0.893	1.23±1.39	1.11±1.21	0.09	0.795	0.82 ± 1.13	0.64±1.11	0.16	0.650
	95& CI	1.54–3.03	0.87–1.82			1.50–2.59	1.35–2.64			0.56–1.89	0.53–1.68			0.28 – 1.35	0.11–1.16		
Handicaps (0-8)	Mean±SD	1.64±1.36	0.58±0.71	0.97	0.008**	1.76±1.60	1.58±1.37	0.12	0.732	1.00±1.58	1.00±1.11	0	1.000	0.52±1.23	0.35±0.70	0.16	0.611
	95& CI	0.99–2.28	0.24–0.91			0.99–2.52	0.92–2.23			0.24–1.75	0.47–1.52			0.06–1.10	0.01–0.68		
Total score(0-56)	Mean±SD	22.94±5.89	13.05±4.73	1.85	0.001**	21.76±6.82	19.05±7.09	0.38	0.265	13.00±8.1	12.94±6.72	0.01	0.982	7.47±7.15	7.52±5.936	0.01	0.979
	95& CI	20.14–25.74	10.80–15.29			18.51–25.00	15.68–22.42			9.15–16.85	9.74–16.13			4.07–10.86	4.70–10.33		

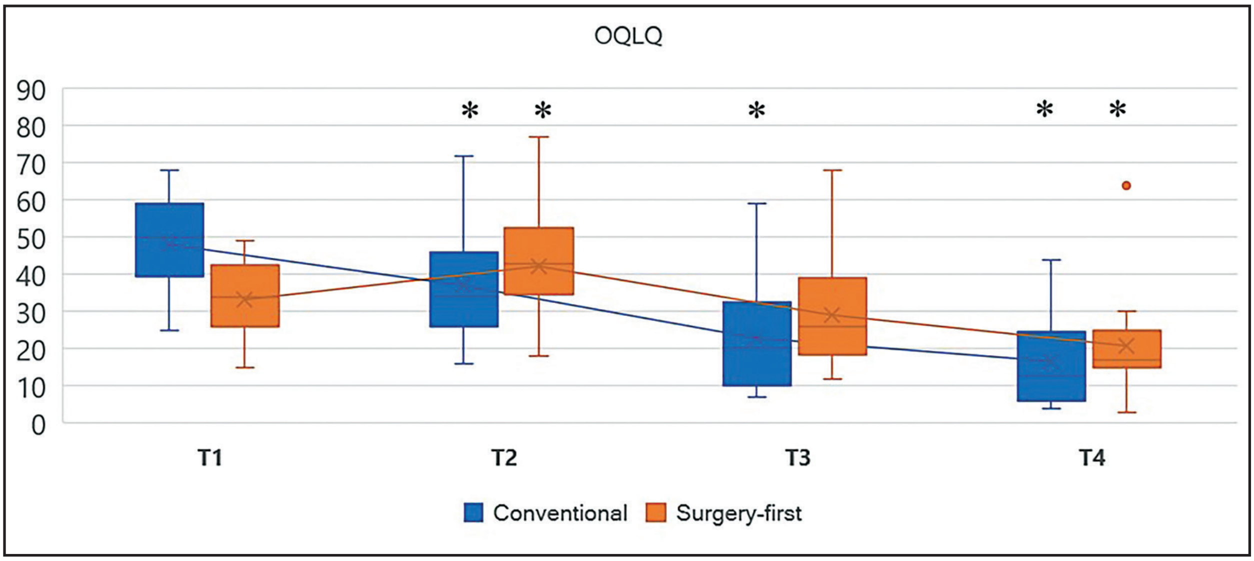

Figure 1: The average overall scores of the Orthognathic Quality of Life Questionnaire (OQLQ) in the preoperative period (T1) and at 1 month (T2), 3 months (T3), and 6 months after surgery (T4).
**indicates a statistically significant difference (p<0.05) when compared with T1 within each group.*

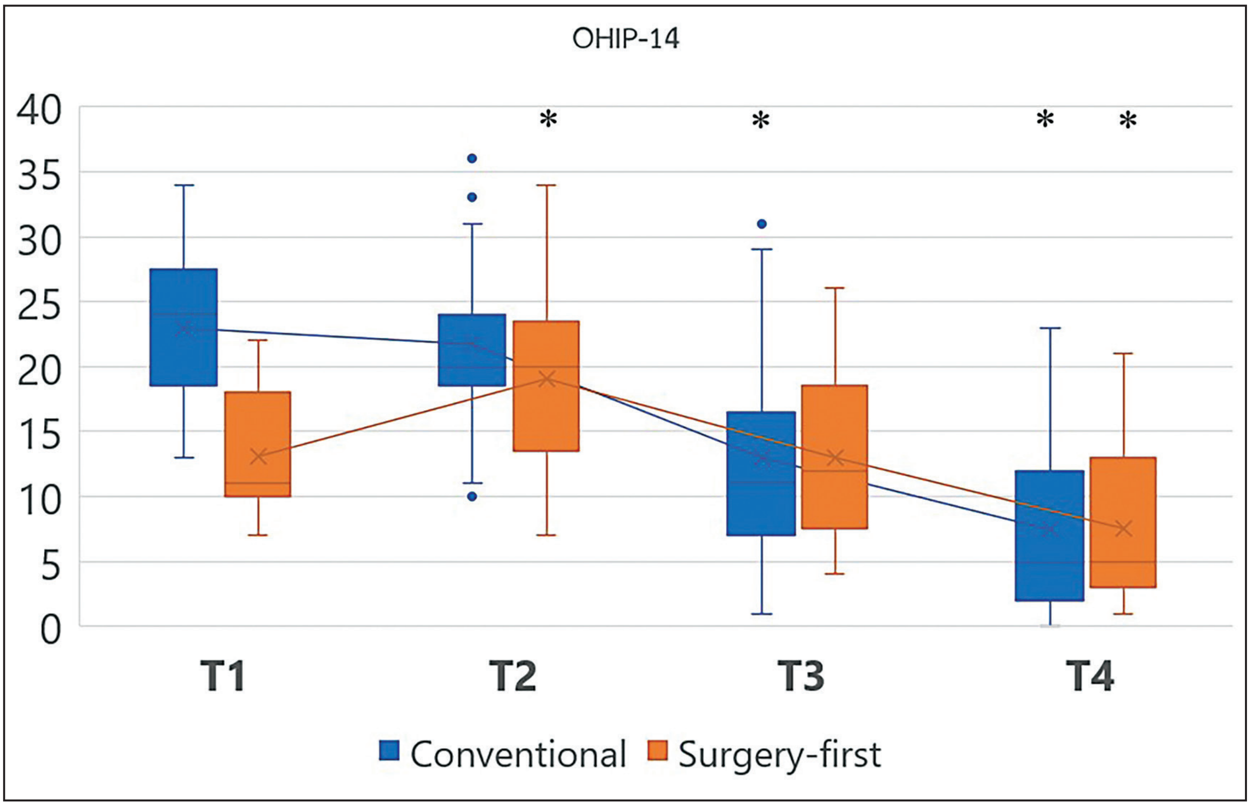

Figure 2: The mean scores of the overall outcome of the Oral Health Impact Profile (OHIP-14) in the preoperative period (T1) and at 1 month (T2), 3 months (T3), and 6 months after surgery (T4).
**indicates a statistically significant difference (p<0.05) when compared with T1 within each group.*

integrated both OHIP-14 and OQLQ to comprehensively evaluate the QoL of patients. Using this method, comprehensive and specific information is provided on individuals undergoing orthognathic surgery for skeletal deformities.

This study translated the OQLQ into a Thai version using the cross-cultural adaptation method.(18) This version aligns with the research conducted by Patchenee and Chaiprakit.(28) This approach was used in the study conducted by Nammontri(29), who translate the OHIP-14 into Thai. Likewise, Saensutthawijit *et al.*,(30) employed this method to create the Thai version of the Dental Health Impact Profile.

No changes in QoL were observed between the CS and SF groups after surgery using the OHIP-14. This finding is consistent with previous studies.(6)

This study found a significant improvement in QoL, as indicated by the OQLQ scores, from 1 to 3 months following surgery in participants undergoing CS. This finding is consistent with those of Park *et al.*(11)

When the average OHIP-14 scores were used to compare the QoL of patients treated with CS, a significant increase in QoL was observed 6 months after surgery. This observation is consistent with Baherimoghaddam *et al.*(23)

At 6 months after surgery, the total scores of OQLQ and OHIP-14 in both groups improved significantly, consistent with previous studies.(11,13,31)

According to the absence of a pre-surgical orthodontic phase in the SF orthognathic surgery, the surgery procedure may cause instability of the bite following surgery.(5) Excessive overjet and a deep Curve of Spee, which affect bite stability and the patient's QoL, were found to produce more mandibular displacement in SF than in CS.(5,32) Consequently, this study found that patients in the SF group had lower QoL on both the OQLQ and OHIP-14 at 1 month following surgery compared to the CS group. At 1 month after surgery, the SF group experienced changes in their occlusion. Changes in occlusion affect individuals physically and psychologically, resulting in decreased QoL across all domains with no statistical significance.

Although there was no statistically significant difference in postoperative QoL between patients undergoing CS and those undergoing SF, the QoL improved in both groups after surgery. Both orthognathic surgery approaches contribute to improving the QoL of patients with skeletal deformities.(33) Therefore, the selection of the surgical approach relies on the agreement between the patient and doctor.

A key limitation of this study is the absence of pre treatment quality of life (QoL) assessments for the CS group, which has resulted in an unequal baseline QoL between the two groups.

Conclusions

There was no significant difference in QoL between the patients treated with CS or SF approaches at 1, 3, and 6 months after surgery. In the CS group, there was an improvement in QOL, with statistically significant differences observed at 1 month (OQLQ) and 3 months (OHIP-14) post-surgery compared to the preoperative period.

In the SF group, there was a significant decline in QoL at 1 month after surgery, followed by a significant improvement at 6 months after surgery (OQLQ and OHIP-14), compared to the preoperative period.

Both surgical approaches resulted in noticeable improvements in the patients' QoL. Therefore, the selection of the surgical approach relies on the agreement between the patient and doctor.

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Original Article

Factors Influencing the Success of Non Vascularized Iliac Bone Graft for Mandibular Reconstruction: A Retrospective Study of 26 Cases

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Abstract

Objective: This study aimed to identify the prognostic factors influencing the success of nonvascularized iliac bone grafts for mandibular reconstruction.

Methods: This was a retrospective cohort study conducted at a single center, involving 26 patients who underwent segmental mandibulectomy followed by nonvascularized iliac bone grafts between 2012 and 2022 at the Oral and Maxillofacial Surgery Unit, Buddhachinaraj Phitsanulok Hospital. Data were collected by reviewing electronic medical records and radiographic images. Patients who had received vascularized bone grafts or had a history of head and neck irradiation therapy were excluded from the study. The patients were classified into two groups: successful and failed. Success was defined as clinical and radiographic evidence of bone continuity, a graft resorption rate not exceeding 30% of the initial height, and no evidence of chronic infection for at least 6 months.

Results: Successful bone grafting was achieved in 19 patients (73.1%). Multivariable risk difference regression analysis identified that the factors influencing graft incorporation were jaw immobilization using reconstruction plates with maxillomandibular fixation for at least 21 days (RD 63.0; 95% CI 33.1, 93.0; $p<0.001$) and long segmental block graft design (51.3%; 95% CI 16.9, 85.7; $p<0.003$). A clinically significant factor, although statistically insignificant, was the duration of plate stabilization, which should ideally range from 172 to 232 days prior to plate removal. The sample size constituted a limitation of this study.

Conclusions: Nonvascularized bone grafting remains a viable option for reconstructing mandibular segmental defects. The factors influencing graft stability can help improve clinical outcomes.

Keywords: iliac crest bone graft, mandibular reconstruction, nonvascularized bone graft

Introduction

The mandible is involved in masticatory and swallowing functions, including airway maintenance and facial aesthetics. The presence of facial injuries, aggressive benign lesions, malignant neoplasms, or extensive osteomyelitis can result in loss of mandibular function and deformities.(1) Currently, autogenous vascularized and nonvascularized bone grafts are the standard treatment for mandibular reconstruction.(2-4)

The vascularized bone grafts (VBGs) commonly used are the fibula free flap (FFF) and deep circumflex iliac artery free flap (DCIA), which are considered the ideal choice for mandibular reconstruction because these grafts provide a robust blood supply and adequate tissue support.(4) This reconstructive technique is used for large bone defects or non unions. The immediate blood supply to the graft, established through anastomosis, helps maintain the viability of the graft, preventing necrosis and enhancing the chances of successful integration into the recipient bone. The living bone cells within the graft continue their natural processes, such as osteogenesis and remodeling, leading to more effective and faster healing. However, limitations of the VBG option remain due to greater donor site morbidity, longer operating times, and the need for a hospital with specialized resources and surgeons with specific knowledge and expertise.(5,6)

Nonvascularized bone grafts (NVBGs), a type of bone grafting procedure used to promote bone healing and regeneration, involve the transplantation of bone tissue without its original blood supply. Graft healing relies on the recipient site to revascularize the transplanted bone, which is slower and more limited compared to VBGs. Generally, NVBGs are used for small to moderate bone defects, non-unions, and in dental procedures such as alveolar ridge augmentation and socket preservation.(6) The iliac crest bones are often preferred, and rib grafts are recommended for lateral defect reconstruction.(1,7) The advantages of NVBGs include easier harvesting and transplantation, less donor site morbidity, and shorter surgical periods and hospital stays compared to VBGs.(5,8) This operation can be performed in general and regional hospitals with sufficient resources.

Although NVBGs are often considered in patients with no history of radiation exposure to the head and neck area, they are typically used when the amount of recipient soft tissue is adequate, and the defect length is no more than 6 cm. However, it remains controversial whether NVBGs should be used for mandibular defects greater than 6 cm in patients with sufficient soft tissue beds. Other factors that promote bone healing, such as graft stability and the type of rigid reconstruction plate used to aid graft incorporation, also play a role.(1,9-12) The treatment approach for each patient is determined through a collaborative decision-making process involving both the surgeon and the patient, with careful consideration of donor site morbidity and the anticipated success rate of bone grafting.

The aim of this study is to evaluate the prognostic factors influencing the success of nonvascularized iliac crest bone grafts for mandibular reconstruction over a minimum of six months. Understanding these factors may help in developing clinical practice guidelines and improving patient outcomes.

Materials and Methods

This was a prognostic factor study using a retrospective observational cohort design that recruited 26 patients who had undergone segmental mandibulectomy for ameloblastoma of the mandible, followed by either immediate or delayed NVBGs. The surgeries were performed by a single surgeon at a single center in the Oral and Maxillofacial Surgery Unit Buddhachinaraj Phitsanulok Hospital, between 2012 and 2022. This study was submitted to and approved by the Buddhachinaraj Phitsanulok Hospital Institutional Review Board (COA No.153/2566, HREC No.172/2566).

Data were collected by reviewing electronic medical and surgical records, including radiographic data taken preoperatively, intraoperatively, and postoperatively. The inclusion criteria were patients diagnosed with benign mandibular neoplasms who had undergone NVBGs for segmental mandibular defects. Patients with a history of head and neck radiation therapy, those who had undergone VBGs for mandibular reconstruction, and those with incomplete data were excluded from the study.

To investigate the factors influencing the success of NVBGs in a cohort of 26 patients, it was determined that the mean duration of jaw immobilization in the success group was 34.3±14.4 days, while in the failure group it was 8.6±15.7 days, revealing a statistically significant difference. Consequently, the means were estimated using STATA 16.1 software (Stata Corp LLC, United States), employing a one-sided test with a significance level of 0.05 and a power of 0.90. The failure-to-success ratio was calculated to be 0.37 (7:19), indicating that the sample sizes for the success and failure groups should be at least 12 and 5, respectively.

The independent variable was NVBGs for segmental mandibular defects after mandibulectomy for benign tumors. All patients were diagnosed with intraosseous ameloblastoma and underwent preoperative oral prophylaxis for dental caries or periodontal disease. A two-layer watertight intraoral closure was performed after tumor resection. All NVBGs were harvested from the anterior iliac crest using a mono-corticocancellous block graft technique (Figure1). Preoperative antibiotic prophylaxis was administered intravenously and continued for 10-14 days postoperatively, either intravenously or orally. The autogenous block grafts were used to reconstruct mandibular defects in either immediate or delayed reconstruction. In cases where there is a risk of losing soft tissue bed coverage at the recipient site due to the expansion of a large benign tumor, particularly in regions involving the symphysis, delayed reconstruction is typically the preferred approach.[1,2] The grafts were stabilized with either a 2.7-mm non locking or a 2.4-mm locking reconstruction plate system (Synthes) due to the requirement for sufficient strength. Jaw immobilization with MMF was performed for graft stability during the immediate postoperative phase for 4–6 weeks, unless contraindicated (e.g., risk of airway compromised due to respiratory disease, seizure, or patient refusal). Radiographic examinations were performed within the first week postoperatively and at least every 4–6 months thereafter. Reconstruction plates were removed after 6–8 months to prevent stress shielding once graft stabilization was achieved (Figure 2).

The main outcome variable was the classification of patients into successful and failed graft incorporation groups. Successful bone graft incorporation was defined as clinical and radiographic evidence of bone continuity, with graft resorption not exceeding 30% of the initial height and no evidence of chronic infection for at least 6 months. The bone resorption rate was assessed by comparing the grafted bone height obtained from immediate postoperative panoramic radiographs with measurements taken from radiographs at the 6 month follow-up.

Covariates included preoperative demographics, perioperative and postoperative factors such as gender, age, smoking and alcohol consumption history, body weight, height, BMI, comorbidities, mandibular defect classification, symphysis involvement, bone graft length, timing of reconstruction, graft stabilization method, MMF time, plate stabilization time, long segmental block graft design union , graft infection, and total graft loss.

Mandibular defect locations were classified according to Brown *et al.*'s classification of mandibular defects based on the four corners of the mandible, as this classification closely matched our patient data.[13] The classifications are: Class I (angle) - lateral defect at the angle without involvement of the ipsilateral canine or condyle; Class Ic (angle and condyle) - lateral defect involving the condyle (disarticulation); Class II (angle and canine) - hemi-mandibulectomy defect involving the ipsilateral angle and canine but sparing the contralateral canine or condyle; Class IIc (angle, canine, and condyle) - hemi-mandibulectomy defect involving the ipsilateral condyle; Class III (both canines) - anterior mandibulectomy defect involving both canines but sparing both angles; Class IV (both canines and at least one angle) - extensive anterior mandibulectomy defect involving both canines and at least one angle; Class IVc (both canines and at least one condyle) - extensive anterior mandibulectomy defect involving both canines and at least one condyle (Figure 3). After harvesting the anterior iliac crest bone graft, it was determined that the size of the monocortico-cancellous bone graft was primarily 4–7 cm in length and 4–5 cm in width. Therefore, the bone shape must be adjusted before securing it with a reconstruction plate, ensuring that the bone height does not exceed 3 cm to prevent occlusal interference. Total bone graft length and the design of long segmental block grafts were assessed using panoramic radiographs and by measuring the retained reconstruction plate in each patient, regardless of whether a 2.7-mm non locking plate or a 2.4-mm locking plate was utilized. The distance between the plate holes of the 2.7-mm non locking and 2.4-mm locking reconstruction plates is 0.8 cm.

This research was analyzed using the STATA 16.1 software (Stata Corp LLC, United States) to compare data between the successful and failed groups. Categorical variables were analyzed using the exact probability test, while numerical variables were analyzed using the Student's t-test and the Wilcoxon rank-sum test to compare means and standard deviations (SD). Factors influencing graft incorporation success were analyzed using multivariable risk difference regression, with results presented as risk differences (RD %).

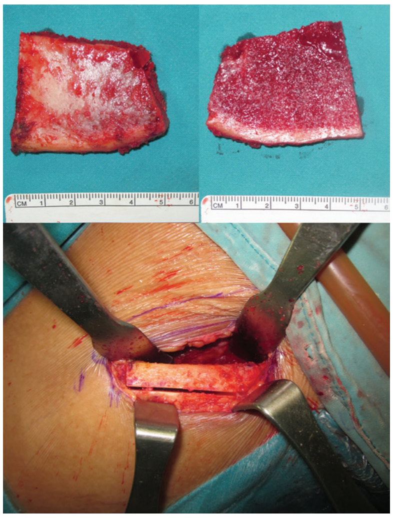

Figure 1: The mono-corticocancellous block graft technique was performed using bone harvested from the anterior iliac crest.

Results

A total of 26 patients with NVBGs were included in this study. We found that 19 patients achieved iliac crest bone graft incorporation following segmental mandibulectomy, representing a success rate of 73.1% (Table 1). When comparing the two groups (successful and failed), the majority of patients were male in both groups (57.9% vs. 71.4%). However, females had a higher proportion of success (42.1% vs. 28.6%, respectively). The patients in the success group were younger on average (36.4±12.3 years vs. 44.1±9.9 years, respectively). However, gender and age were not found to be significant variables in predicting graft failure (p=0.668 and p=0.146, respectively). The mean weight was statistically higher in the success group (74.3±13.6 kg vs. 59.3±6.2 kg; p=0.010), as was the mean height (164.9±5.9 cm vs. 157.3±6.9 cm; p=0.009). However, the mean BMI, although higher in the success group, was not significantly different (27.3±4.7 vs. 23.85±2.9; p=0.088).The majority of patients were non smokers (68.4% vs. 57.1%; p=0.661) and non drinkers (73.7% vs. 71.4%; p=1.000), and most had no comorbidities (68.4% vs. 85.7%; p=0.629), though none of these factors were statistically significant.

Factors related to mandibular defect classification found that Class II and IIc had the highest success rate (52.6% vs. 28.6%), followed by Class I (31.6% vs. 28.6%) and Class III (15.8% vs. 42.8%), respectively. The majority of mandibular defects in the success group did not involve the symphysis (68.4% vs. 28.6%), whereas the majority of failures did involve the symphysis (31.6% vs. 71.4%).The total bone graft length in the successful group was slightly shorter than in the failed group (8.8±1.5 cm vs. 9.1±2.2 cm), though this difference was not statistically significant (p=0.688).The majority of reconstructions were immediate (73.7% vs. 57.1%), followed by delayed reconstruction (26.3% vs. 42.9%), though this difference was also not statistically significant (p=0.635). There was a higher usage of 2.4-mm locking reconstruction plates (68.4% vs. 71.4%) compared to 2.7-mm non locking plates (31.6% vs. 28.6%), though again, there was no significant difference (p=1.000).

The duration of MMF in the success group was significantly longer than in the failed group (34.3±14.4 days vs. 8.6±15.7 days; p=0.005). The duration of plate stabilization, however, was not significantly different between the two groups (198.4±27.6 days vs. 195.7±39 days; p=0.841). Regarding bone graft intersegment union, complete bone union was achieved by designing a long segmental graft block (≥ 4 cm), as measured by panoramic radiographs, and by using the size of the reconstruction plate as a reference. This outcome was statistically more common in the success group compared to the failure group (84% vs. 14.3%; p=0.002). Of the seven failed cases, two were associated with postoperative localized infections, and one required complete graft removal (Table 2).

The multivariable risk difference regression analysis identified six variables that predicted prognostic success factors (Table 3). These factors included female gender (RD -12.3; 95% CI -35.5, 10.9; p=0.299), age (RD 0.15; 95% CI -0.6, 0.9; p=0.672), body weight (RD -0.01; 95% CI -0.7, 0.7; p=0.957), and height (RD -5.9; 95% CI -2.4, 1.2; p=0.529). The factors most significantly influencing graft stability and incorporation were MMF time of at least 21 days (RD 63.0; 95% CI 33.1, 93.0; p<0.001) (Figure 4) and long segmental block graft design (51.3%; 95% CI 16.9, 85.7; p<0.003). An important clinical factor, although statistically insignificant, was the recommended duration of plate stabilization, which should be between 172 and 232 days before plate removal (Figure 5).

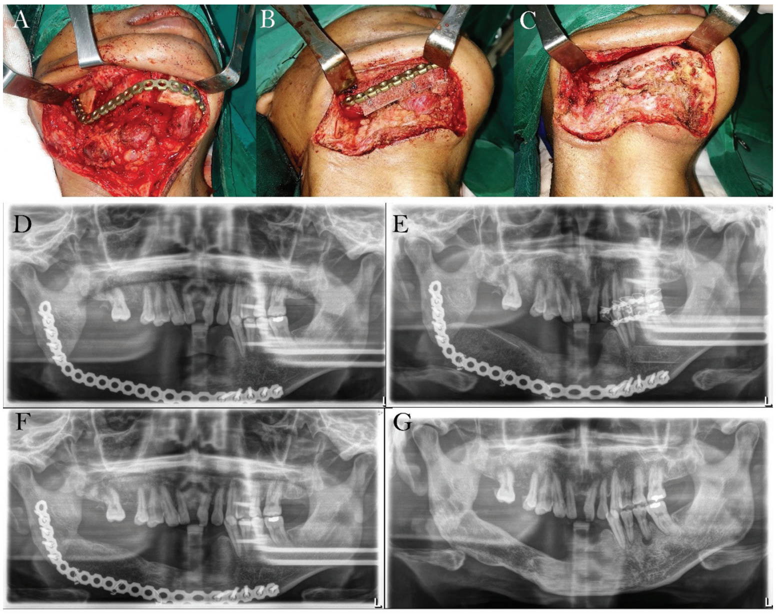

Figure 2: A. A 2.4-mm locking-type reconstruction plate stabilizes the mandibular defect after tumor resection.
B. A delayed nonvascularized iliac bone graft was performed 72 days after tumor resection.
C. A nonvascularized bone graft was performed 185 days after plate removal.
D. The radiographic examination reveals a 2.4-mm locking-type reconstruction plate that stabilizes the mandibular defect following tumor resection.
E. The radiographic examination indicates that a delayed non vascularized iliac bone graft was conducted 72 days following tumor resection.
F. The radiographic examination demonstrates incorporation of the iliac bone graft at 178 days.
G. The radiographic examination revealed the transplanted bone at 242 days.

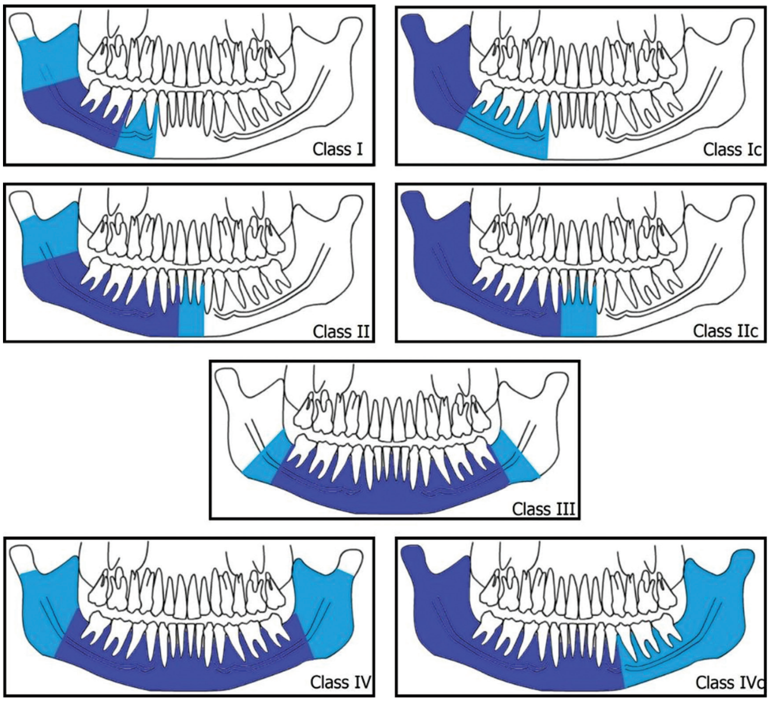

Figure 3: Brown *et al*.'s classification of mandibular defects.[13] Mean defect size (Dark blue); total extent of mandibular defect (blue).

Table 1: Preoperative demographic and intraoperative information.

Characteristics	Success (n=19)		Failure (n=7)		*p*-value
	n	(%)	n	(%)	
Gender					
Male	11	57.9	5	71.4	0.668
Female	8	42.1	2	28.6	
Age(year), mean±SD	36.4	(±12.3)	44.1	(±9.9)	0.146
Body weight(kg), mean±SD	74.3	(±13.6)	59.3	(±6.2)	0.010
Height(cm), mean±SD	164.9	(±5.9)	157.3	(±6.9)	0.009
BMI, mean±SD	27.3	(±4.7)	23.85	(±2.9)	0.088
Smoking					
Yes	6	31.6	3	42.9	0.661
No	13	68.4	4	57.1	
Alcohol consumption					
Yes	5	26.3	2	28.6	1.000
No	14	73.7	5	71.4	
Comorbidities					
No	13	68.4	6	85.7	0.629
Hypertension	3	15.8	0	0	0.540
Diabetes mellitus	2	10.5	0	0	1.000
Hypothyroidism	1	5.3	0	0	1.000
Adrenal insufficiency	0	0	1	14.3	0.269
Brown classification of mandibular defects					
Class I and Ic	6	31.6	2	28.6	1.000
Class II and IIc	10	52.6	2	28.6	0.391
Class III	3	15.8	3	42.8	0.293
Class IV and IVc	0	0	0	0	0
Symphysis involvement	6	31.6	5	71.4	0.095
No symphysis involvement	13	68.4	2	28.6	
Total bone graft length(cm),mean±SD	8.8	(±1.5)	9.1	(±2.2)	0.688
Total bone graft length of mandibular defect					
Class I and Ic (cm),mean±SD	9.1	(±1.7)	10.7	(±0.5)	0.196
Class II and IIc (cm),mean±SD	9.1	(±1.3)	9.6	(±3.9)	0.402
Class III (cm),mean±SD	7.1	(±0.6)	7.7	(±1.3)	0.011
Class IV and IVc (cm),mean±SD	0	0	0	0	0
Stage of reconstructions					
Immediate reconstruction (Primary)	14	73.7	4	57.1	0.635
Delayed reconstruction (Secondary)	5	26.3	3	42.9	
Graft stabilization methods					
2.4-mm. locking type of reconstruction plate	13	68.4	5	71.4	1.000
2.7-mm. non locking type of reconstruction plate	6	31.6	2	28.6	

Abbreviations: SD, standard deviation

Table 2: Postoperative information.

Characteristics	Success (n=19)		Failure (n=7)		*p*-value
	n	(%)	n	(%)	
Maxillomandibular fixation time (days), mean±SD	34.3	(±14.4)	8.6	(±15.7)	0.005
Plate stabilization time (days), mean±SD	198.4	(±27.6)	195.7	(±39)	0.841
Long segmental block graft design union (≥4 cm)					
Complete bone union, n(%)	16	84.2	1	14.3	0.002
Incomplete bone union, n(%)	3	15.8	6	85.7	
Graft infection, n(%)	0	0	2	28.57	0.065
Total graft loss, n(%)	0	0	1	14.29	0.269

Abbreviations: SD, standard deviation

Table 3: Multivariable risk difference regression analysis.

Characteristics	Success (n=19) n (%)	Failure (n=7) n (%)	Adjust RD (%)	95% CI	*p*-value
Female (n, %)	8 (42.1)	2 (28.6)	-12.3	-35.5, 10.9	0.299
Age (year)	36.4 (±12.3)	44.1 (±9.9)	0.15	-0.6, 0.9	0.672
Body weight (kg)	74.3 (±13.6)	59.3 (±6.2)	-0.01	-0.7, 0.7	0.957
Height (cm)	164.9 (±5.9)	157.3 (±6.9)	-5.9	-2.4, 1.2	0.529
MMF time (day)	34.3 (±14.4)	8.6 (±15.7)	-	-	-
MMF time ≥21 days	-	-	63.0	33.1, 93.0	<0.001
Long segmental block graft design (n,%)	16 (84.2)	1 (14.3)	51.3	16.9, 85.7	0.003

Abbreviations: CI, Confident interval; RD, Risk difference

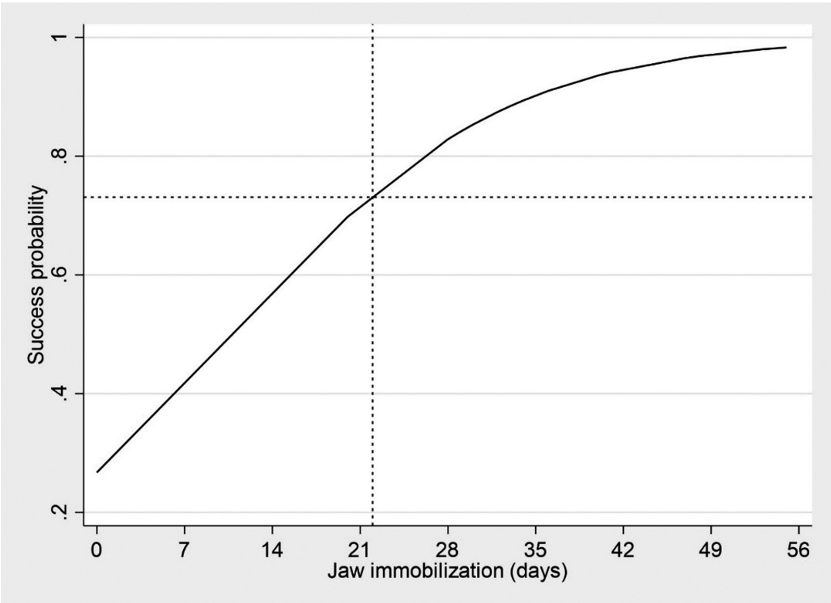

Figure 4: The graph illustrates the probability of success, indicating that the duration of jaw immobilization with maxillomandibular fixation should be a minimum of 21 days.

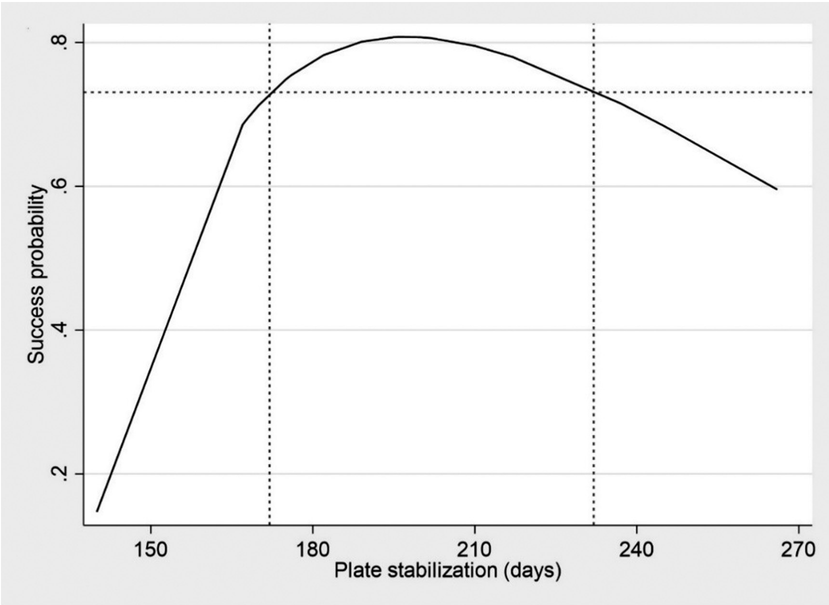

Figure 5: The graph illustrates the probability of success, suggesting that the optimal duration for plate stabilization should range between 172 days and 232 days.

Discussion

Nonvascularized autogenous bone grafting for mandibular segmental defect reconstruction is a challenging operation, often performed following corrective surgery for benign neoplasms, trauma, or infection. The benefits of this technique include less donor site morbidity, reduced operation time, and shorter hospital stays compared to vascularized bone graft techniques. Therefore, NVBG is a viable option for mandibular reconstruction.

Generally, the factors that affect surgical technique and graft incorporation success include the quality of soft tissue coverage without infection, non irradiated tissue, and graft stabilization techniques. However, it is essential to study other biomechanical factors that play a significant role in successful bone graft incorporation to improve clinical practice guidelines and treatment outcomes.

The purpose of this study was to identify the variables affecting the success or failure of nonvascularized iliac bone grafts in subjects who underwent mandibular reconstruction over an 11-year period. Based on this research, the success rate of non vascularized iliac crest bone grafting for mandibular reconstruction was 73.1%. We used the autogenous corticocancellous technique to obtain cancellous bone cells and rigid cortex for stabilization.(14) The results of this study were similar to previous studies, which found varying success rates for NVBGs: 69%(15), 76%(16), 87.6%(1), and 90%.(12) Patient factors that influenced success in this study included weight (p=0.010) and height (p=0.009), while no significant differences were found for gender (p=0.668), age (p=0.146), BMI (p=0.088), and comorbidities (p=0.629).

According to a retrospective study by Schileve *et al*.,(17) gender and age were not associated with bone graft success rates. However, no studies have shown a correlation between weight, height, and bone graft success. Most patients in this study were non smokers and non drinkers, which aligns with several previous studies that reported lower success rates in smokers due to a compromised pool of osteoprogenitor cells at the recipient site.(3,5,9,18)

Regarding the classification of mandibular defects Brown *et al*.,(13), the majority of successes were observed in Class II (52.6%) and Class I (31.6%) defects, located in the lateral mandible. These regions had higher success rates than defects involving the symphysis or central areas. Moura *et al*.,(1) reported lower complication rates in lateral defects, and graft incorporation of NVBGs was comparable to that of VBGs. On the contrary, defects involving the symphysis or extending across the midline of the mandible can lead to complications such as wound dehiscence, plate exposure, and graft infection.(4,8,23)

Due to the limitations of sample size, we found that the mean length of the total bone graft in the success group was shorter than in the failure group, but we were still unable to determine the optimal graft length for success. Pogrel *et al*.,[16] found that grafts 6 cm or shorter had a 17% failure rate, while grafts over 12 cm had a 75% failure rate. They recommended NVBGs for secondary mandibular reconstruction for defects less than 9 cm in length. Foster *et al*.,[15] reported success rates of 75% for defects smaller than 6 cm, while defects measuring 6-10 cm and 10-14 cm had lower success rates of 46% and 40%, respectively. Although previous studies have shown lower success rates for grafts longer than 6 cm, it remains controversial whether NVBGs should be used in defects greater than 6 cm, especially in patients with sufficient soft tissue coverage. Other factors such as graft stability and rigid fixation types also promote bone healing.[1,9-12]

A comparison of reconstruction stages in this study found that most patients underwent primary reconstruction, while those with large tumors or tumors involving the symphysis region received secondary bone grafts. However, no correlation was found between reconstruction stage and success rate. Generally, primary reconstruction is preferred as it allows for cosmetic and functional restoration after ablative surgery in the same episode, facilitating early bone union and rehabilitation. The advantages of this procedure include abundant vascular supply to the recipient site, reduced scar formation, and fewer surgeries, which benefit the patient's psychological well-being. However, the intraoral approach increases the risk of infection due to oral bacterial contamination.[16,19] In contrast, secondary procedures, while associated with compromised vascularity due to scar tissue, can be successful with NVBGs. Studies have reported success using secondary or delayed reconstruction via extraoral approaches, typically performed 6-8 weeks after tumor resection to prevent oral contamination.[9,16,20,21] The reconstruction plates used in this study were 2.4-mm locking types and 2.7-mm non locking types, with no significant differences in success between the two types. Kim *et al.,*[22] found that locking reconstruction plates were associated with fewer complications than non locking plates in patients undergoing mandibular resection for head and neck cancer.

In addition to rigid reconstruction plates, maxillomandibular fixation (MMF) for jaw immobilization is essential for success. We found that MMF for at least 21 days increased the success rate by up to 63%. Tidstrom *et al.,*[20] reported MMF durations of 1-6 weeks in their study, and Gadre *et al*.[8] found an 88.5% success rate with 10-12 days of MMF. We recommend a minimum of 21 days of MMF to enhance graft stability and reduce micro-movements that could disrupt angiogenesis and creeping substitution. The evaluation of mono-cortico-cancellous bone graft union in this study showed that the segmental block grafts longer than or equal to 4 cm achieved greater stability than shorter grafts. However, several reports indicate that bone grafting demonstrates success in cases where the total bone graft size is less than or equal to 6 cm.[15,16] In addition, mechanical stability is crucial for revascularization and cellular differentiation at the recipient site. Granulation tissue and fibrosis may form between the graft and recipient bone when stabilization is insufficient.[5] Although reconstruction plates provide significant stability, some studies suggest plate removal at six months to prevent stress shielding.[8,16]

Conclusions

Mandibular segmental defect reconstruction using autogenous nonvascularized iliac bone grafts remains a useful option for non irradiated recipient sites. Factors influencing graft stability, such as reconstruction plates with maxillomandibular fixation and long block bone graft design, can improve clinical outcomes, reduce bone resorption, and maintain mandibular continuity. These findings can help inform clinical practice guidelines. However, due to the limitations of this study, further research and systematic data collection are needed.

List of abbreviations used

AICBG	Anterior iliac crest bone graft
CI	Confident interval
DCIA	Deep circumflex iliac artery free flap
FFF	Fibula free flap
MMF	Maxillomandibular fixation
NVBG	Nonvascularized bone graft
RD	Risk different
SD	Standard deviation
VBG	Vascularized bone graft

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Conflicts of Interest

The author declares no potential conflicts of interest related to this research.

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The Connection Between Dietary Awareness and Eating Behavior in Thai-Peranakan Seniors: A Study of Members of the Thai Peranakan Association

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Abstract

Objective: This study explored the relationship between dietary awareness and eating behavior among Thai-Peranakan senior citizens.

Methods: Using a cross-sectional design, we sampled 94 individuals aged 60 and above (mean age=66.56), all of whom were members of the Thai Peranakan Association. This group included both males and females who met the inclusion criteria of having normal communication and memory abilities. Data were gathered through structured interviews and analyzed with Spearman's Correlation.

Results: Personal factors such as living status and family income significantly influenced the eating behavior of Thai-Peranakan senior citizens at the 0.01 level. The Spearman's correlation showed significant relationships among accurate self-assessment and eating behavior, with correlation coefficients (r) of 0.29 at the 0.05 level.

Conclusions: Personal factors and dietary awareness, specifically accurate self-assessment, are pivotal in shaping the eating behavior of Thai-Peranakan senior citizens. Enhancing these aspects can lead to better eating behavior and overall well-being among this demographic.

Keywords: awareness, dietary, eating bahaviors, senior

Introduction

The global population has recently surpassed 7.8 billions, with approximately 962 million individuals aged 60 and over, representing 14% of the total population. In the Association of Southeast Asian Nation (ASEAN) region, several countries are recognized as aging societies, where the senior citizens population exceeds 10%. Notably, Singapore and Thailand have senior citizens populations exceeding 20%. In Thailand, approximately 65.06 million people reside, with those aged 60 and over accounting for 20.08% of this demographic.(1)

Dietary habits among older adults are influenced by various factors, including underlying health conditions, solitary eating habits, and limited access to nutrient-rich food options.(2-4) These dietary patterns significantly contribute to the increased risk of malnutrition, particularly among low-income individuals and those with chronic illnesses. Furthermore, reduced physical activity and limited social interaction can lead to depression, diminishing interest in food and exacerbating nutritional deficiencies.(5) A critical challenge in addressing these issues is the lack of nutritional knowledge and awareness. Research, including studies by Beelen *et al.,*(6) highlights the significant relationship between nutrition knowledge and dietary intake. A descriptive cross-sectional study by Rungsiyanont S and Sakoolnamarka SS(7) focused on older adults in Samut Prakan and Nakhon Nayok.(8) Their research found that personal factors like income, education level, and living with family positively influenced older adults' eating behavior.

This issue is particularly relevant for the Peranakan community, also known as Baba-Nyonya, an ethnic group that blends Chinese and Malay cultures, primarily found in Malaysia, Singapore, Indonesia, and Thailand. Their distinctive traditional attire and unique language, Baba Malay, reflect their cultural identity. The Peranakan's rich cultural heritage is also showcased in their cuisine, which combines ingredients and flavors from both Chinese and Malay traditions. Signature dishes like laksa and nasi lemak feature complex cooking techniques such as braising, steaming, and stir-frying, often with a wide variety of spices.(9-12)

While these dishes are flavorful, they often contain unhealthy nutrients–saturated fats, sodium, and sugar–that can negatively impact health when consumed in excess. For example, laksa, nasi lemak, and ayam buah keluak are high in fats, increasing the risk of heart disease, while sambal, babi pongteh, and asam pedas are rich in sodium, contributing to high blood pressure. Desserts like kueh lapis and pengat pisang are high in sugar, raising the risk of diabetes and weight gain. Deep-fried foods, such as keropok and spring rolls, add unhealthy fats and excess calories. Despite these health risks, these dishes are favored for their rich flavors, quick preparation, cultural significance, and affordability. Healthier alternatives, like grilled fish, sayur lodeh, and gado-gado, are often perceived as less satisfying and require more preparation time.(13,14)

In Thailand, the Peranakan community is concentrated in coastal provinces like Phuket, Phang Nga, and Trang, where their mixed Thai-Chinese heritage, strongly influenced by Hokkien traditions, is most prominent. Focusing on Thai-Peranakan seniors is crucial to understanding how cultural and socioeconomic factors influence their dietary habits. As they balance preserving traditional food practices with adapting to modern lifestyles, these seniors offer a valuable case study in the intersection of cultural preservation and health challenges. Their dietary choices highlight the complexities of maintaining traditional eating habits while addressing contemporary health concerns.

This study was designed to foster inclusivity in health research, ensuring that the experiences and needs of diverse communities were considered in the development of effective health strategies. Addressing the unique challenges faced by Peranakan seniors enabled a more holistic approach to nutrition education and intervention. Additionally, initiatives to preserve and promote Peranakan traditions, such as cultural and historical learning centers, played a vital role in maintaining this heritage as an integral part of Thailand's identity.(15)

Proper nutrition is crucial for aging populations, enhancing quality of life and preventing age-related health issues. Improving dietary awareness can lead to healthier eating behaviors, reducing the risk of malnutrition and related health problems. This research provided valuable insights for policymakers and health programs aimed at supporting Peranakan seniors while preserving their cultural heritage.

The "Nine Dietary Guidelines," established by the Nutrition Division of the Department of Health and Mahidol University in 1999, provided a framework for promoting healthy eating choices.[16] Additionally, Goleman's Mixed Model of Emotional Intelligence helped enhance self-awareness and decision-making in dietary behaviors, empowering Peranakan seniors to make informed choices while appreciating their cultural significance.[17] This study investigated the correlation between dietary awareness and eating behavior among Thai-Peranakan seniors, filling gaps in nutritional knowledge and guiding health interventions.

Given the unique culinary heritage of the Peranakan community, it was essential to explore how traditional food practices influenced dietary choices. This understanding helped identify areas for targeted health interventions

Objective

This study aimed to explore how Thai-Peranakan senior citizens' nutrition awareness influenced their eating behavior

Materials and Methods

Study design

This study was a cross-sectional study was approved by the Ethics Committee for Research on Humans and Animals, Srinakharinwirot University, with the approval number SWUEC671089 prior to data collection.

Sample size calculation

The study population consisted of 168 adults aged 60 years or older, all of whom were members of the Thai Peranakan Association. This group included both males and females who met the inclusion criteria, which were as follows:

Inclusion criteria:

1. Participants did not have any chronic conditions that affect their ability to eat, such as diabetes, hypertension, liver disease, kidney disease, gastrointestinal disorders, or arthritis.

2. Participants did not have any physical or mental impairments that prevent them from caring for themselves, including those who have lost both arms or legs, those with depression or psychiatric disorders, or those with visual impairments.

3. Participants were willing to take part in the study.

Exclusion criteria:

1. Individuals who were unable to choose or prepare their own food, such as those residing in nursing homes.

2. Individuals whose relatives or caregivers select and prepared their meals without the person having a say in the menu.

3. Individuals who had dietary restrictions or limited food intake due to health conditions or physician instructions.

In the end, 94 individuals were contacted and agreed to participate in the study.

Data collection procedure

Before collecting data, training was provided to interviewers on methods and the use of the interview form. A preliminary test was conducted with a similar group to the sample to refine the questionnaire. The data was collected through direct interviews with the sample, organized via the Thai Peranakan Association. The researcher, along with village Public Health Volunteers (PHVs), conducted 20-minute interviews. The questionnaire was crafted using culturally appropriate language and terminology to ensure participants fully understood and accurately responded. The questions focused on foods and eating behavior specific to the Thai Peranakan culture.

Instruments

Data collection: Data was collected using an interview questionnaire designed in Thai, covering three main aspects:

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

Nutrition awareness: This section was based on Goleman's Mixed Model of Emotional Intelligence Theory[16], with adaptations from research by Sakoolnamarka and Rungsiyanont.[7,8] Questions focused on three key areas: Emotional awareness (10 items), Accurate self-assessment (9 items), and Self-confidence (7 items). Each question was rated on a 5-point scale: Very much = 5, Much = 4, Moderate = 3, Little = 2, Very little = 1, Not at all = 0. Scores for negatively worded questions were reversed to maintain consistency. Therefore, a higher score indicates the presence of healthy nutrition awareness behavior, while a lower score indicates unhealthy nutrition awareness

Eating behavior: The eating behavior questionnaire 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.(16) This ensured a comprehensive assessment of the participants' dietary habits. The questions were crafted using culturally appropriate language and terminology to facilitate understanding, focusing on foods and dietary practices unique to the Thai-Peranakan culture, such as halal dietary laws and traditional foods, enhancing relevance and accuracy. The questionnaire consisted of 12 items: 6 items reflecting positive behaviors and 6 items reflecting negative behaviors, measuring the frequency of eating behavior among older adults over a specified period. Therefore, a higher score indicates the presence of healthy eating behavior, while a lower score indicates unhealthy eating behavior

The scoring interpretation for nutrition awareness and eating behavior consisted of five levels as follows:

Very low (0-1.0): Indicates a very poor understanding of nutrition.

Low (1.01-2.00): Participants in this range have limited awareness or suboptimal eating behavior

Moderate (2.01-3.00): Shows average awareness and behaviors.

High (3.01-4.00): Reflects good awareness and generally healthy eating practices.

Very high (4.01-5.0): Indicates excellent awareness and eating behavior.

Data analysis

The normal distribution of the mean scores for dietary awareness and eating behavior was assessed using Skewness and Kurtosis statistics. Dietary awareness scores for all three aspects showed Skewness and Kurtosis values between -1.00 and 1.00, indicating a non-normal distribution.

Statistical methods used:

Descriptive statistics:

Percentage was used to describe the proportion of the sample in each category of data.

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

Inferential statistics:

Mann-Whitney U Test was used to test differences in mean scores between independent groups, such as gender, living with family, and eating behavior.

Kruskal-Wallis H Test was used to test differences in mean scores between groups with more than two categories, such as highest education level, total family income, and eating behavior.

Spearman’s correlation was used to analyze the relationship between two variables, specifically the relationship between the three components of dietary awareness and eating behavior.

Data quality control

To ensure the internal consistency reliability of the questionnaire, assessments were conducted. Three experts verified content validity and appropriateness of wording, ensuring an Index of Item-Objective Congruence (IOC) of at least 0.50 for all items. Reliability was further evaluated by administering the questionnaire to a similar population aged 50-59 years, involving 30 individuals. The Cronbach’s alpha coefficient for each section exceeded 0.70, indicating good reliability.

Additionally, 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 94 senior citizens aged 60 years and above, 34 were male (36.17%) and 60 were female (63.83%), with an average age of 66.56 years. And most age 60-69 (87.23%) with the majority (87.23%) falling within the 60-69 age range.

The majority had a highest education level of primary school or below (56 individuals, 59.57%), and most had a monthly income of 25,001 THB or above (44 individuals, 46.81%). Additionally, 83 individuals (88.30%) were living with family members, as shown in Table 1

1.1 Emotional awareness

The survey results showed that the overall emotional awareness score was at a moderate level, averaging 2.91 points. This indicates that respondents are somewhat aware of the emotional factors influencing their food choices, but may not consistently apply this awareness in their daily eating behavior. Respondents scored very high in feeling guilty about eating junk food (4.40 points) and in enjoying eating with others (4.02 points). Conversely,

Table 1: Personal factors of the population.

Demographic data	Amount	Percentage (%)
Gender		
Male	34	36.17
Female	60	63.83
Education		
Primary school and under	56	59.57
Secondary school	17	18.10
High school and above	21	22.33
Family income		
Under 10,000 THB	9	9.57
10,001 - 25,000 THB	41	43.62
25,001 - or above	44	46.81
Living status		
Live alone	11	11.70
Live with others	83	88.30
Total	**94**	**100**

Table 2: Emotional awareness in population.

Items	Mean	SD	Interpret
You are not guilty for not finishing a meal	2.84	1.15	Moderate
You feel good when finishing drinks after a meal	2.84	1.01	Moderate
It's alright not to eat the meal on time	2.58	1.23	Moderate
You are guilty after consuming unhealthy food	3.48	0.97	High
You are feeling guilty for having a leftover meal	3.04	1.05	High
You feel good when get to eat as much as you like	1.32	0.55	Low
You are contented when having soft drinks as when you feeling thirsty/hungry	2.70	1.31	Moderate
You love to eat with others	4.02	1.15	Very high
It's alright to eat unhealthy food which you like	1.88	1.56	Low
You feel guilty for eating junk foods	4.40	0.99	Very high
Total	**2.91**	**0.90**	**Moderate**

Table 3: Accurate self-assessment in population.

Items	Mean	SD	Interpret
You will not stop eating until you feel full even though you have already had a lot.	1.98	1.02	Low
You do realize that you are not able to chew on hard food.	4.18	0.63	Very high
You eat tempting desserts even when you recognize that it is not good for your health.	2.96	1.26	Moderate
You are willing to eat dislike vegetables	3.66	0.92	High
You are able to recognize when you are full	3.48	0.71	High
You do recognize your ability to consume spicy food	3.46	0.73	High
You are able to indicate the healthy food portions in your daily consumption	3.30	0.76	High
You are able to indicate the unhealthy food portions in your daily consumption	3.36	0.80	High
You are able to estimate the energy from each meal	2.92	0.97	Moderate
Total	**3.25**	**0.73**	**High**

the lowest scores were recorded for feeling alright about eating unhealthy food they liked (1.88 points) and feeling good about eating as much as they wanted (1.32 points), as detailed in Table 2.

1.2 Accurate self-assessment

The results showed that the overall accurate self-assessment score was at a high level, averaging 3.25 points, suggesting that senior citizens generally had a good understanding of their own abilities and limitations related to self assessment. They scored highest in recognizing their inability to chew hard food (4.18 points). Most of the results were at a high level, with the lowest score being in their tendency to continue eating until they felt full, even if they had already consumed a lot (1.98 points), as detailed in Table 3.

1.3 Self-confidence

Overall self-confidence scores were at a high level, averaging 3.46 points. the respondents generally view themselves as capable and competent in managing challenges. They showed the highest confidence in ensuring their meals are healthy (3.82 points) and in eating enough fruits and vegetables daily (3.76 points). The lowest score, though still high, was in their ability to guide others on the risks and benefits of meals (3.06 points), as detailed in Table 4.

The assessment of eating behavior showed that the overall eating behavior score was at a high level, averaging 3.44 points, indicating that respondents generally exhibit healthy eating behaviors. Senior citizens scored very high in eating properly washed and cooked food (4.60 points). They also scored very high in drinking water and beverages from trustworthy sources (4.28 points), avoiding alcoholic drinks (4.22 points), and eating more than three meals a day (4.20 points). The lowest score was observed in the consumption of rich, cheesy, mellow, or savory foods, as detailed in Table 5.

The personal factors data were analyzed alongside the average scores for dietary awareness in three areas: emotional awareness, accurate self-assessment, and self-confidence, as well as the eating behavior of senior citizens. The analysis utilized the Mann-Whitney U Test and Kruskal-Wallis H Test. The findings revealed that personal factors such as family income and living status significantly influenced eating behavior (p=0.01) and accurate self-assessment (p<0.05). Additionally, family income significantly impacted both accurate self-assessment (p=0.01) and emotional awareness (p=0.01). Senior citizens with higher incomes and stronger social support systems such as living with other family members were likely to exhibit better eating behavior.

The data were analyzed to determine the relationships between the variables using Spearman's correlation. This involved examining the average scores for personal awareness of nutrition in three areas–emotional awareness, accurate self-assessment, and self-confidence and the eating behavior of senior citizens. The analysis revealed that accurate self-assessment was the only aspect of dietary awareness significantly correlated with eating behavior at the 0.05 level. The correlation coefficients (r) ranged from 0.29, indicating a low positive correlation, as shown in Table 7. However, the mean difference test across different groups did not yield statistically significant results. Thus, accurate self-assessment of eating habits showed a weak but significant positive correlation with eating behavior.

Discussion

This study demonstrates that personal factors, such as living status and family income, significantly influence the eating behavior of Thai-Peranakan senior citizens across all aspects at the 0.01 level. Additionally, accurate self-assessment significantly impacts their eating behavior at the 0.05 level. It was found that Thai-Peranakan senior citizens who are more aware of their dietary needs tend to make healthier food choices, which positively influence their overall eating behavior, aligning with global research findings.

The report titled "The Influence of Income and Prices on Global Dietary Patterns" by the USDA's Economic Research Service investigates how income and prices influence dietary habits worldwide.(18) It highlights that worldwide changes in eating habits contribute to a rise in obesity and related noncommunicable diseases, particularly in low- and middle-income countries. Another study(19) examines how family income influences eating behavior, emphasizing that lower-income families often face challenges in maintaining healthy eating habits due to financial constraints.

Research by Sakoolnamarka SS and Rungsiyanont S(20), found that personal factors like family income and living status, were significant positive relation (p<0.01) to eating behavior. Similarly, a study published in BMC

Table 4: Self-confidence in population.

Items	Mean	SD	Interpret
You assure that you have ability to make healthy food choices for yourself	3.20	0.80	High
You assure that you have ability to make healthy food suggestions for your family	3.62	0.90	High
You assure that you eat with confident that your meals are healthy.	3.82	0.77	High
You assure that you eat enough fruits and vegetables on a daily basis	3.76	0.59	High
You assure that you have ability to guide others on risk and benefits of their meals	3.06	0.84	High
You assure that you have ability to control food portions in each meal	3.52	0.74	High
You mistrust of the food taste which was cooked by others	3.26	0.94	High
Total	**3.46**	**0.82**	**High**

Table 5: Eating behavior in population.

Items	Mean	SD	Interpret
Eat desserts; Thai traditional dessert, cake and pastries.	2.84	0.74	Moderate
Eat more than 3 meals a day.	4.20	0.76	Very high
Drink soda and soft drink.	3.38	1.05	High
Avoid alcohol beverages.	4.22	1.13	Very high
Eat vegetables and root vegetables.	3.12	1.15	High
Eat crunchy snacks; chips, potato chips, dried fruits.	3.22	1.38	High
Eat variety of foods that provide the five major nutrients.	3.42	0.91	High
Eat whole grains and whole grain products.	3.00	1.37	Moderate
Eat protein foods; egg(s), nuts, meat.	3.32	1.06	High
Eat rich cheesy, mellow or/and savory food.	1.72	1.31	Low
Drink water and drinks from trustworthy sources.	4.28	0.83	Very high
Eat properly washed and cooked food.	4.60	0.61	Very high
Total	**3.44**	**0.91**	**High**

Table 6: The relationship between personal factors, dietary awareness and eating behavior.

Personal factors	Statistic	1. Dietary Awareness			Eating behavior
		Emotional awareness	Accurate self-assessment	Self-confidence	
Gender	Mann-Whitney U Test	p=0.77	p=0.16	p=0.89	p=0.39
Education	Kruskal-Wallis H Test	p=0.65	p=0.30	p=0.24	p=0.69
Family income	Kruskal-Wallis H Test	p=0.31	**p=0.04***	p=0.11	**p=0.01***
Living status	Mann-Whitney U Test	**p=0.01***	p=0.15	p=0.10	**p=0.01***

Table 7: The relationship between dietary awareness and eating behavior, analyzed using Spearman's correlation to identify influencing factors within the population.

		Emotional awareness	Accurate self-assessment	Self-confidence	Eating behavior
Eating behavior	Correlation	0.11	0.29*	0.13	1
	Sig(2-tailed)	0.43	0.04	0.37	
	N	94	94	94	94
* Sig < 0.05					

Public Health[21] analyzed the association between lifestyle behaviors and life satisfaction among older adults in Thailand. This study found that living status, among other factors, significantly influenced eating behavior and overall life satisfaction.

In Europe, a study[22] explored how living status, specifically eating alone, influences eating behavior among older adults. It found that those who ate alone were less likely to eat three meals a day and had different food intake patterns compared to those who ate with others.

Accurate self-assessment is closely related to self-compassion, both of which are pivotal for mental well-being, addressing different aspects of self-perception and emotional response. A relevant study[23] explores how self-compassion impacts eating behavior, particularly under stress. The findings indicate that higher levels of self-compassion are associated with healthier dietary choices and reduced food cravings after stress.

Similarly, research by Sakoolnamarka SS and Rungsiyanont S[20,24], found that the three factors of nutritional awareness were significantly correlated with food consumption behaviors. Emotional awareness, including accurate self-assessment, showed a significant positive correlation (r=0.48 and 0.29, respectively, $p<0.01$).

These findings underscore the importance of considering cultural and socioeconomic factors in dietary interventions. Policymakers and healthcare providers should tailor programs to the specific needs of Thai-Peranakan senior citizens, incorporating cultural dietary practices and enhancing nutritional awareness through targeted self-assessment strategies. This holistic approach can improve the overall health and well-being of the elderly while preserving their rich cultural heritage.

To incorporate cultural and socioeconomic factors into dietary interventions for Thai-Peranakan senior citizens, it is essential to understand their unique traditions, food practices, and community dynamics. Interventions should respect and integrate culturally familiar ingredients, cooking methods, and communal dining habits, ensuring that programs are both practical and culturally acceptable. Engaging with the community through interviews and observations allows for a deeper understanding of their needs, while recognizing the role of family support in shaping eating behaviors. By tailoring programs to address both cultural preferences and socioeconomic challenges, such as income and food access, interventions can promote healthier eating behavior while preserving the cultural identity of the Thai-Peranakan community.

The relationship between demographic factors such as family income, living status, and dietary awareness aligns with findings from previous research. Studies have shown that individuals with higher socioeconomic status, including higher family income, tend to have better access to nutritional information and healthier food choices. Similarly, living status plays a crucial role in dietary habits. Seniors who live with family members often benefit from social support and encouragement to maintain healthy eating behaviors, whereas those living alone may experience challenges such as social isolation, limited resources, and reduced access to nutritious food, which can negatively affect their dietary awareness.

Recommendations for improving eating behavior among Thai-Peranakan senior citizens

To improve the eating behavior and overall well-being of Thai-Peranakan senior citizens while honoring their cultural heritage, several strategies can be implemented. Nutritional counseling through one-on-one sessions with culturally aware nutritionists can offer personalized guidance, aiding seniors in making healthier food choices. Family involvement is crucial, encouraging relatives to support and participate in meal planning and preparation. Incorporating healthy eating messages into cultural celebrations can highlight traditional yet nutritious dishes.

Additionally, developing engaging tools like games, quizzes, or apps can help seniors assess their eating habits and nutritional knowledge, providing immediate feedback and making learning enjoyable. Establishing support groups enables seniors to share experiences, challenges, and successes, enhancing motivation and providing practical advice. Together, these initiatives form a comprehensive approach to promoting a healthier lifestyle among Thai-Peranakan senior citizens.

Limitations

The sample of 94 participants was limited to members of the Thai-Peranakan Association, which was the primary indicator of Peranakan identity, as this community is defined by cultural practices, language, and customs rather than nationality or religion. While there may have been Peranakan individuals outside the Association, there were no clear markers to identify them, making membership the most reliable criterion. This small, non-representative sample limited the generalizability of the findings. Additionally, self-reported data collected through interviews introduced potential biases, and the cross-sectional design prevented causal conclusions about the relationship between dietary awareness and eating behavior.

Recommendations for further study

Conduct longitudinal studies to establish causal relationships between dietary awareness and eating behaviors over time. This approach can help identify changes and trends in eating behavior among senior citizens. Additionally, implement and evaluate targeted interventions designed to improve dietary awareness and eating behaviors, such as educational workshops, counseling sessions, and interactive tools.

Compare the eating behavior of Thai-Peranakan senior citizens with those of other cultural groups within Thailand and Southeast Asia. These comparisons can provide insights into how cultural factors influence eating behavior, helping to tailor more effective, culturally-sensitive dietary interventions.

Conclusions

Dietary awareness factor, specifically accurate self-assessment, were significantly corelated with Thai-Peranakan senior citizens' eating behavior at the 0.05 level.

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Conflicts of Interest

The authors declare no conflict of interest.

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Case Report

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Connective Tissue Graft May Compensate for Residual Bone Defect of the Implant in the Esthetic Zone: A Case Report with 7-year Follow-up

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Abstract

The present case report aimed to demonstrate the case using a connective tissue graft (CTG) to compensate for a residual defect after guided bone regeneration (GBR) in the anterior maxillary area. An extensive number of studies have reported successful outcomes of horizontal bone augmentation, but it was also demonstrated that a complete resolution of the defect may not be achieved in all cases. In the present case report, the patient underwent implant placement simultaneously with GBR at the anterior maxillary area. After 4 months, partial regeneration of the initial defect was observed. To compensate for such residual defect, a CTG was applied. Other expectations by the CTG were to enhance tissue volume and phenotype. The final prosthesis was delivered after 3 months. Up to 7 years, favorable radiographic and clinical situations were observed. In conclusion, a CTG may compensate for residual bone defect of the implant in the esthetic zone.

Keywords: connective tissue graft, esthetics, guided bone regeneration

Introduction

The presence of a sufficient amount of peri-implant bone is one of the prerequisites for the long-term stability of the implant.(1,2) Several studies have been performed to decide how much peri-implant bone thickness is required.(3-5) In a retrospective clinical study involving 2,667 implants, it was shown that, at the time of abutment connection, the peri-implant bone loss on the facial surface was related to the facial bone thickness after preparation of implant osteotomy.(5) The study demonstrated a trend that smaller initial facial bone thickness led to greater vertical bone loss on the facial aspect. Moreover, more than 1.8 mm of bone thickness was required to prevent facial loss. In a recent preclinical study by Monje *et al.,*(3) the implant groups with more than and less than 1.5 mm of buccal bone thickness were compared, revealing that more than 1.5 mm of buccal bone thickness prevented physiologic bone resorption and reduced pathologic bone loss.(3)

As mentioned above, an ideal goal for peri-implant bone augmentation would be an establishment of 1.5-2.0 mm of bone thickness upon the implant surface. For this purpose, many approaches are used, such as guided bone regeneration (GBR), ridge splitting, and block bone graft, demonstrating successful outcomes.(6-8) However, one can argue whether a complete resolution of the defect is feasible. In one clinical study, the authors tested two GBR techniques with and without the addition of autogenous bone chips.(9) Interestingly, two GBR groups led to a low frequency of total defect resolution (<25%). This may indicate that residual defects can be encountered more frequently than predicted. If it is true of our everyday clinical practice, clinicians should prepare countermeasures. Residual defects may lead to insufficient tissue profile or vulnerability to mucosal recession.

This case report aimed to demonstrate using a connective tissue graft to compensate for a residual defect after GBR in the anterior maxillary area.

Case report

A 31-year-old woman visited the Department of Periodontology, Kyung Hee University Dental Hospital, Seoul, Korea, for implant treatment in the maxillary anterior region. The patient had an endodontic failure at the maxillary right permanent central incisor. After further discussion on a prognosis of the affected tooth in the Department of Conservative Dentistry, an extraction of the problematic tooth was finally decided.

The tooth was atraumatically extracted with forceps, and then a removal temporary prosthesis was delivered. Implant placement was scheduled at 8 weeks post-extraction. Soft tissue was almost healed with slight coronal depression at this time. Cone-beam computed tomography (CBCT) revealed the presence of thin labial bone residue and insufficient bone tissue in the extraction socket. No residual apical lesion was observed (Figure 1).

Under local anesthesia with 2% lidocaine containing 1:100,000 epinephrine (Yuhan Co., Seoul, Korea), a mucoperiosteal flap was elevated. After sequential drilling, a bone-level implant was placed (Straumann BL Ø 4.1 x 10 mm, Straumann, Basel, Switzerland), and a cover screw (0.5-mm height, Straumann) was connected. The implant was positioned relatively buccally considering "the concept of comfort and danger zone," proposed at the Third ITI Consensus Conference in 2003.(10) On the labial surface of the implant, a long dehiscence-type defect was found, and contour bone augmentation was performed. Deproteinized bovine bone mineral (Bio-Oss, Geilstlich, Wolhusen, Switzerland) was grafted on the exposed implant surface and the adjacent areas, exceeding the neighboring bony envelope. Then, a collagen membrane (Bio-Gdie, Geistlich) was trimmed with scissors and applied to fully cover the grafted bone particles. The coronal end of the membrane was tucked under the palatal flap. No fixation pin was used. Subsequently, another piece of a collagen membrane was horizontally applied to the implant site. Periosteal releasing incision was performed for tension-free flap closure. Primary flap closure was made using 5-0 and 6-0 nylon suture materials (AILEE Co., Seoul, Korea) (Figure 2).

Antibiotics (Amoxicillin 500 mg, Yuhan, Seoul, Korea) and an analgesic (Loxoprofen 60 mg, Dongwha Pharm, Seoul, Korea) were administered per os 3 times a day for 7 days. The patient was advised to rinse the mouth with 0.12% chlorhexidine solution (Hexamedine, Bukwang, Seoul, Korea) twice a day for 2 weeks. No specific adverse event was observed during the healing.

At 4 months post-implant placement, uncover surgery was planned. The soft tissue appeared sufficiently mature, but some depression was observed at the labiocrestal area. A small flap was reflected to connect a healing abutment, and it was found that unintegrated bone substitute particles and residual bone defect were present at the labial surface of the implant. The remaining height of the defect was roughly 2 mm. Considering the patient's gingival phenotype, the residual defect should be compensated. Among several options, soft tissue augmentation using a connective tissue graft (CTG) was applied. The CTG was harvested from the right side of the hard palate using a single incision approach. The size of the CTG was approximately 6 mm long, 4 mm high, and 1-1.5 mm thick. After connecting a healing abutment (RC Ø5x4 mm, Straumann), the CTG was applied to the residual defect. The coronal end of the CTG was slightly extended on the labial side of the abutment. Due to the small reflection of the flap, the CTG was stably positioned without additional fixation. The flap was then sutured around the healing abutment to protect the CTG from the oral environment (Figure 3).

The healing was pleasant. After 3 months, a final prosthesis (customized titanium abutment and porcelain-fused-zirconia implant crown) was delivered. The patient was recalled twice a year. Up to 7 years of follow-up, stable soft tissue level was observed (Figure 4). Marginal bone level change during the follow-up period was minimal (Figure 5). Other peri-implant indices did not show inflammatory signs (probing pocket depth < 4 mm, bleeding on probing ≤ 1 spot out of 6).

Discussion

In the present study, we demonstrated that CTG may compensate for residual bone defects following GBR in the esthetic zone. The patient underwent standardized bone augmentation surgery, but the defect was not completely resolved. CTG was applied to the residual defect for long-term tissue stability, leading to favorable tissue conditions for up to 7 years.

Among peri-implant defects, the dehiscence-type defect is probably the most-encountered one and horizontal (or lateral) bone augmentation is performed not only for establishing bone structure around implants but also for obtaining sufficient thickness of peri-implant hard tissue. Extensive literature has demonstrated successful outcomes of bone-regenerative treatment for dehiscence-type defects.[8,11] However, one should contemplate specifically whether the defect can be resolved completely, considering the study results showing incomplete bone supply at the defect and shrinkage of the initially augmented dimension.[9,12,13] A recent systematic review based on 28 publications presented that defect resolution was 81.2% on average (4.2 mm defect fill from initial 5.1 mm defect, in height).[8] This indicates that horizontal augmentation may occasionally leave some defects.

For residual defects, several options may be available: 1) leave it as it is, 2) additional bone augmentation, and 3) soft tissue augmentation. If the soft tissue phenotype is thick, the residual defect may be left without augmentation. Jung *et al*.,[14] investigated the effect of small bony dehiscence defect left on the implant without bone augmentation and augmented defect, demonstrating that healthy and stable soft tissue can be established even with bony dehiscence. However, it led to more vertical bone loss compared to the sites with bone augmentation.[14] In a study by Benic *et al.,*[15] they showed more mucosal recession at the immediately placed implant without visible buccal bone (based on CBCT findings).[15] Soft tissue phenotype was not evaluated in those two studies, but one can suspect the phenotype may play a role.

Additional bone augmentation may be considered, but there was no substantial evidence to support it at the insufficiently augmented sites. Such an additional augmentation may require an additional healing period for another submerged healing, which increases total treat-

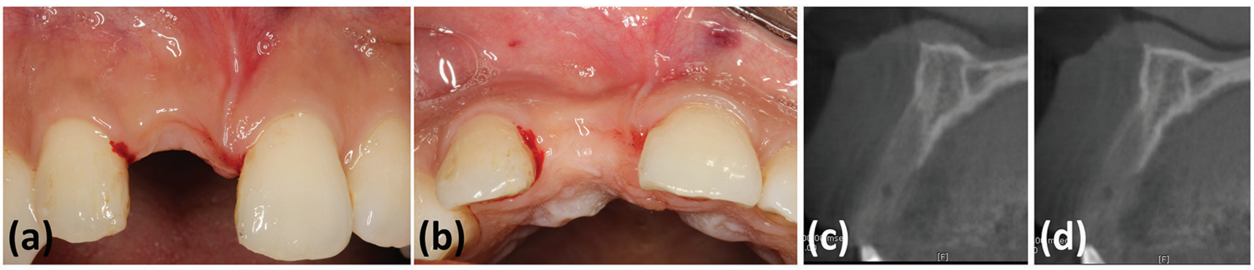

Figure 1: Pre-operative clinical and radiographic situations: (a), facial view of clinical photograph; (b), occlusal view of clinical photograph; (c, d), sagittal view of conebeam computed tomographic scan.

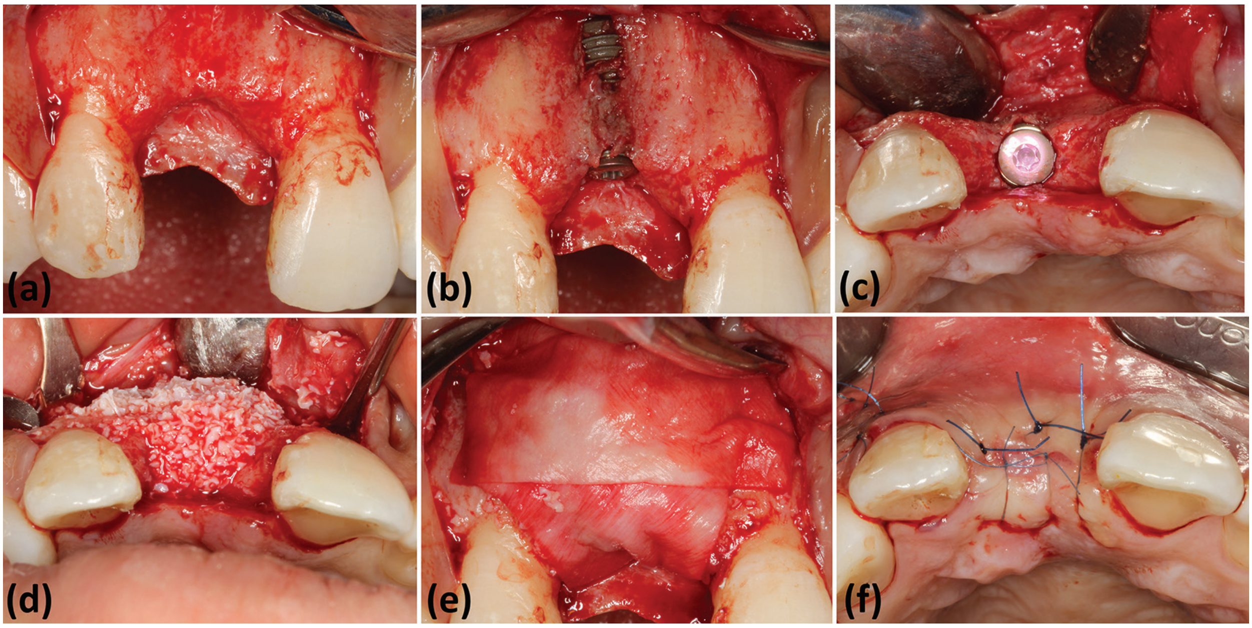

Figure 2: Implant placement and guided bone regeneration: (a), after flap reflection; (b), after implant placement, long dehiscence defect was observed; (c), bucco-oral implant position was not ideal; (d), deproteinized bovine bone mineral was applied; (e), collagen membranes were applied in a double layer manner; (f), primary flap closure.

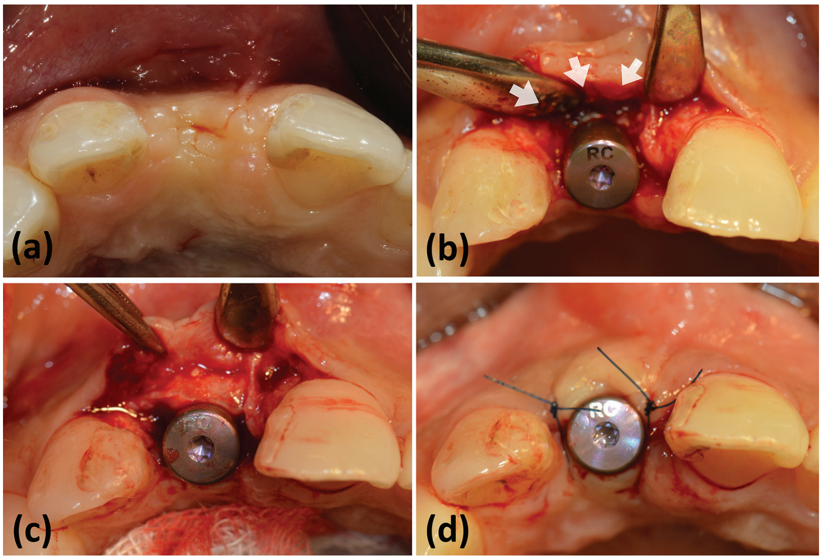

Figure 3: Situation at 4 months post-implant placement: (a), healing was normal, but tissue depression at labio-crestal area was noted; (b), complete defect resolution was not achieved (arrows); (c), connective tissue graft was applied to the residual defect; (d), The flap was sutured around healing abutment.

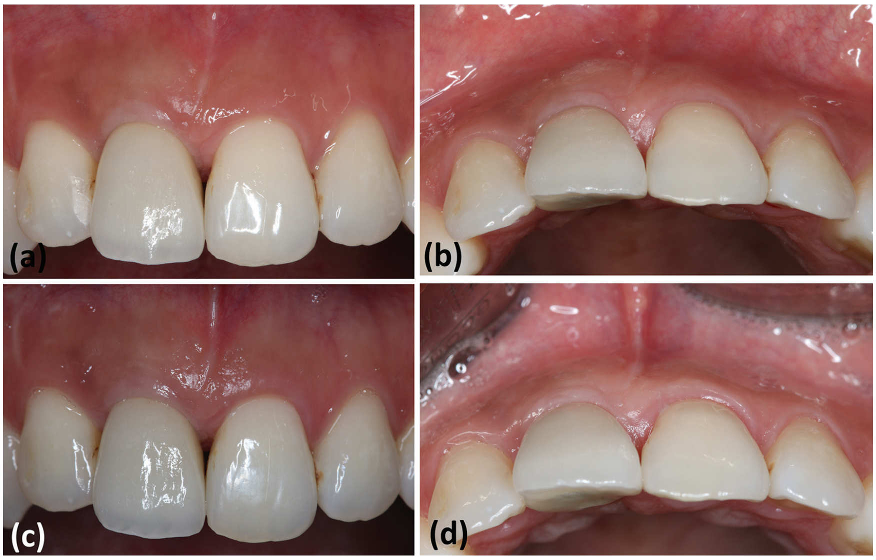

Figure 4: Clinical situation after final prosthesis delivery: (a), facial view at 3 years; (b), occlusal view at 3 years; (c), facial view at 7 years; (d), occlusal view at 7 years.

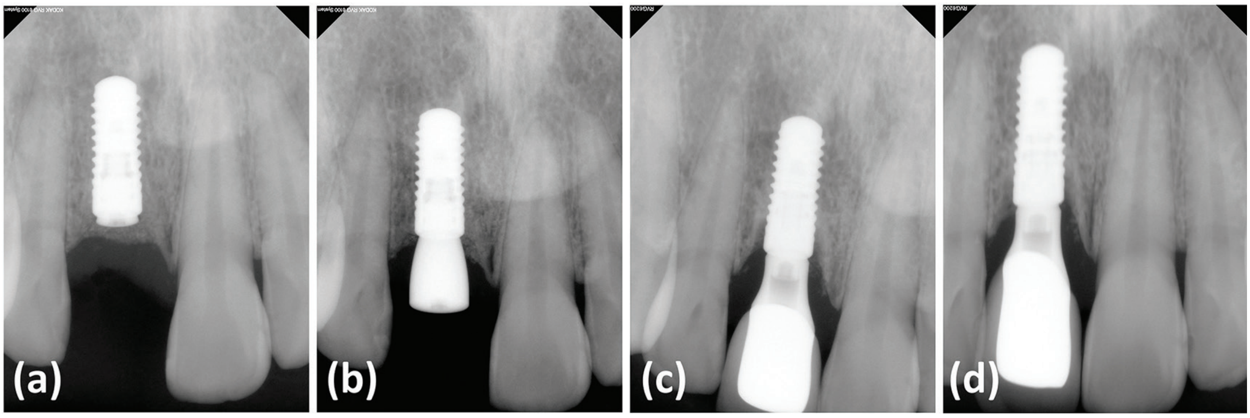

Figure 5: Intraoral radiographic view: (a), immediately after implant placement; (b), after healing abutment connection; (c), at 5 years; (d), at 7 years.

ment time and cost.

The final option is soft tissue augmentation. Recent studies indicate that soft tissue augmentation utillizing autogenous CTGs can produce tissue volume increases equivalent to those achieved with conventional GBR for buccal concavity defects, without necessitating implant surface exposure.(16,17) Furthermore, Stefanini *et al.,*(18) applied a de-epithelized CTG for a small buccal dehiscence defect at implant placement site. They exhibited favorable peri-implant soft tissue conditions and stable marginal bone levels.(18) Even though the number of studies regarding this issue is limited, those studies suggest that soft tissue augmentation may replace GBR for specific situations. In the present case report, the defect was a residue from the prior augmentation. Although the present defect may exhibit distinct characteristics compared to those reported in prior research, the fundamental principle may still be relevant. Moreover, the soft tissue phenotype of the present patient was thin, which might have caused esthetic problems if left unimproved.(19)

The bucco-oral implant position in the present study should be critically appraised. Given the present case, in which some augmented protions were located outside the bony envelope, buccal implant positioning could potentially destabilize the augmented bone. Prior studies have highlighted the critical role of the bony envelope in bone regeneration.[20,21] Thus, more prudent approach for this case might be a more palatal correction of the osteotomy, based on "the concept of comfort and danger zone".[10] Furthermore, it might be advisable to apply more bone substitute material to compensate for resorption.

To prevent insufficient bone regeneration around peri-implant defect, the following strategies may be considered: 1) Employing a healing abutment instead of a cover screw during.[22] Submerged healing can counteract pressure on the implant platform and provide additional space for tissue regeneration. 2) non-resorbable membranes offer greater dimensional stability compared to resorbable membranes.[7] 3) additional bone grafts or collagen-incorporated bone substitutes, placed on top of the implant platform, can prevent displacement of bone graft material.[23,24]

The patient was followed up for a duration of 7 years. Despite no adverse clinical signs or symptoms, the patient should be monitored regularly, considering buccal implant positioning and residual bone defect.

Conclusions

Within the limitations of the present case report, it was shown that 1) simultaneous bone augmentation with implant placement may leave a minor defect, and 2) a CTG can compensate for the residual defect, preventing potential esthetic and biological complications.

Acknowledgments

None

Conflicts of Interest

The authors declare no conflict of interest.

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