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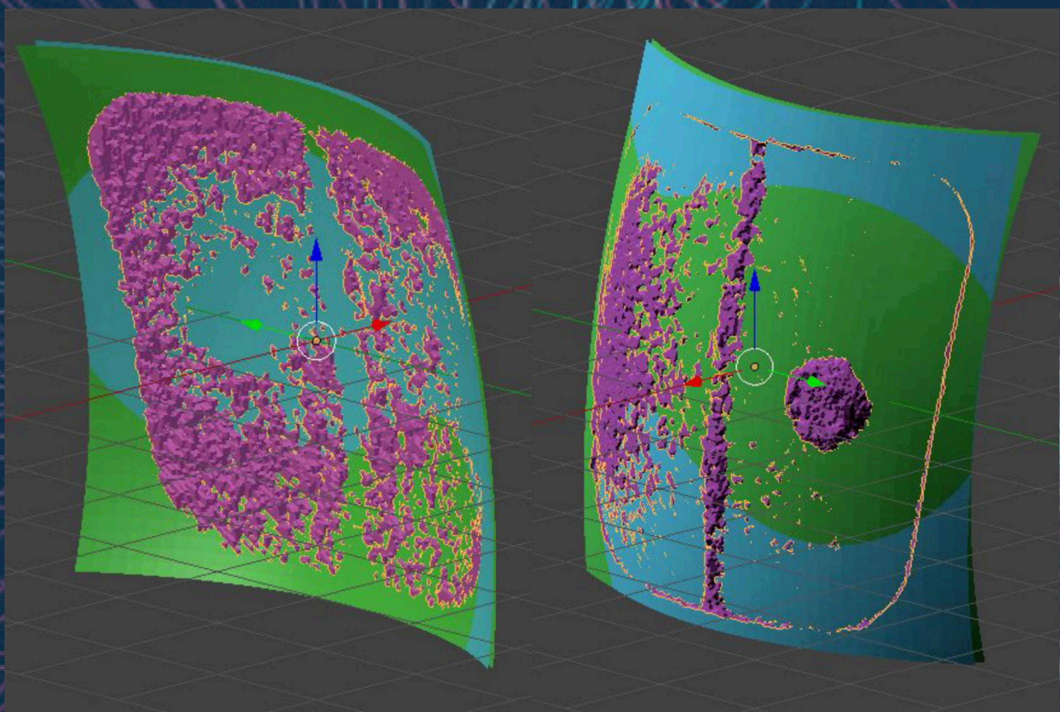

Chiang Mai University's Faculty of Dentistry publishes academic research articles in the newly titled - **Oral Sciences Reports,** which was previously known as *Chiang Mai Dental Journal (CMDJ)*. The journal was originally established for the purposes of publishing academic research articles by the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

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

Aim and Scope of the journal

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

Policy

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

1. The articles must be correct according to academic principles and not duplicate works that have been previously published.
2. The articles will be considered and reviewed through a non-bias process by concealing the names of authors and related persons in the considered documents while also concealing the names of the experts and reviewers who review the articles (double-blind review).
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Asian Citation Index (ACI)
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Editorial Board

Types of Submission

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 Original Articles — Original contributions of research reports or unpublished recent academic research to the development and applications in dentistry and related fields.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

D. Systematic Review

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

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

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

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

Formatting of funding source:

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

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

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

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   - Introduction should be focused to place the subject matter in context and to justify the need for the review.
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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).
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   - Conclusion(s) should reach clear conclusions and/or recommendations on the basis of the evidence presented.

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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.
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3. Nomenclature: abbreviations and acronyms should be spelled out the first time they are used in the manuscript or spelled out in tables and figures (if necessary). Units of measure and time require no explanation. Dental nomenclature in the manuscript should be complete words, such as maxillary right central incisor. Numbering of teeth from pictures or tables should follow the FDI two-digit system.
4. Units: use the international system of units (SI). If other units are mentioned, please give their equivalent in SI.
5. Product identification: all products mentioned in the text should be identified with the name of the manufacturer, city, state, and country in parentheses after the first mention of the product, for example, The ceramic crown was cemented on dentin surface with resin cement (RelyX^{TM} U200, 3M ESPE, St. Paul, MN, USA)…

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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.

F. References

Citation in text

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

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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.

3.2. Thesis retrieved from full text database or internet

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

Example:

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

4. *Webpage*

4.1. Webpage with author

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

Example:

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

4.2. Webpage with no authors

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

Example:

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

4.3. Image on a webpage

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

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

Example:

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

5. *Government publications/reports*

5.1. Reports and other government publications

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

Example:

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

5.2. Government reports available online

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

Example:

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

6. *Tables/Figures/Appendices*

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

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

Example:

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

7. *Journal abbreviation source*

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

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Review Article

Glass Hybrid Glass Ionomer Restorative Materials: A Literature Review

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Abstract

The emergence of glass hybrid glass ionomers (GH-GICs) represents a significant innovation in restorative dentistry, addressing the limitations of traditional materials through enhanced mechanical strength, fluoride release, and ease of application. Given the absence of prior comprehensive literature reviews on this topic, this systematic review was conducted to provide general practitioners with essential insights. A comprehensive literature search was performed in the PubMed, Scopus, and Web of Science databases from 2010-2023, using terms related to GH-GICs, their properties, and their clinical performance. The studies included were published in English and included *in vitro* and *in vivo* research as well as randomized controlled trials. Compared with conventional glass ionomers, GH-GICs exhibit improved mechanical properties, fluoride release, and remineralization potential, showing clinical performance comparable to that of resin composites in small to moderate class I and class II posterior restorations. However, limitations such as marginal adaptation, surface wear, and reduced aesthetics persist, particularly in larger restorations. While resin coatings improve initial wear resistance, their limited longevity and reduced fluoride release present additional concerns. GH-GICs remain promising for specific clinical scenarios, especially in high-caries-risk, pediatric, and geriatric patients, but further long-term studies are needed to confirm their efficacy fully and extend their applications.

Keywords: bulk-fill, glass hybrid, glass ionomers, high viscosity, restorative dentistry

Introduction

Resin composites are highly desirable for their aesthetic and physical qualities but are hindered by the time-consuming technique needed, particularly in deep cavities.[1] To simplify procedures and save time, bulk-fill materials such as bulk-fill resin composites and high-viscosity glass ionomer cements (HV-GICs) have been developed.[2,3] Bulk-fill resin composites offer a promising, time-efficient alternative to conventional resin composites for posterior restorations. Nevertheless, further long-term randomized clinical trials are needed to fully validate their clinical effectiveness.[1,2,4]

Recently, HV-GICs have gained attention as bulk-fill materials, combining the benefits of conventional low-viscosity glass ionomer cements with improved handling properties and mechanical strength. The latest advancement in HV-GICs is the introduction of glass hybrid glass ionomer cements (GH-GICs), which are being promoted for broader clinical applicability. This paper reviews the literature on GH-GICs, focusing on their properties, applications, and clinical implications in restoring permanent teeth.

Search strategy and inclusion criteria

A systematic literature search was conducted to identify relevant studies on GH-GICs. The search was performed via electronic databases such as PubMed, Scopus, and Web of Science, with search terms including "glass hybrid glass ionomer," "high-viscosity glass ionomer," "bulk-fill," "restorative dentistry," "Equia Forte," "Equia," "mechanical properties," "clinical performance," and "fluoride release." Boolean operators (AND, OR) were used to refine the search. Studies published in english from 2010-2024 that focused on the properties, clinical applications, and performance of GH-GICs, as well as comparisons with other restorative materials, were included. Both *in vitro* and *in vivo* studies, including randomized controlled trials and laboratory studies, were considered. Duplicates were removed, and articles were screened on the basis of titles, abstracts, and full-text reviews. The reference lists of the selected articles were also examined to ensure comprehensive coverage of the relevant literature.

Results of the literature search

High viscosity glass ionomers

During the 1990s, industry coined the term 'high viscosity glass ionomer cement' to describe improved glass ionomer cement (GIC).[5] These materials contain high-molecular-weight polyacrylic acid and surface-modified fillers, which increase their reactivity and produce high cross-linkages in the set matrix.[6] Additionally, they are mixed in a higher powder–liquid ratio than conventional GICs are, increasing their performance.[7,8]

HV-GICs exhibit superior physical and mechanical properties, particularly in terms of wear resistance, along with a faster setting time, enabling restorations to be completed in a single visit. Compared with their conventional counterparts, they possess a more translucent appearance due to the inclusion of fine glass particles.[7,9] The enhanced attributes of HV-GICs broaden their applications,[6,10-14] making them versatile for various clinical applications where resin composites and amalgams might not perform optimally.[15-24]

Microlaminated GICs have been introduced to widen the indications for using HV-GICs in the posterior region, where HV-GICs are combined with a light-cured coating. In 2007, the Equia restorative system (GC America, Alsip, IL, USA), comprising Equia Fil–a self-adhesive bulk-fill HV-GIC–and Equia Coat–a highly nanofilled light-cured resin coating–was introduced. Equia Fil, was optimized by the manufacturer to enhance cross-linkage within the GIC matrix. Paired with the Equia Coat, it was promoted as a suitable restorative material for posterior stress-bearing restorations.

The clinical performance of high-viscosity glass ionomers

Studies investigating the clinical performance of HV-GICs have demonstrated satisfactory performance in class I[24,26-30] and small-to-medium class II restorations,[9,27,30-32] with some studies recommending limiting the size of medium class II cavities to ensure that they do not exceed half the intercuspal width in the isthmus width.[33] Klinke *et al.,*[30] compared the clinical effectiveness of the Equia system to that of the conventional Fuji IX GP Fast (GC, Tokyo, Japan) coated with Fuji Coat LC (GC, Tokyo, Japan) on permanent posterior teeth in both class I and class II (two and three surfaces) cavities over a 4-year observation period. The results indicated comparable performance between the two materials in class I cavities. However, in class II fillings, the Equia restorative system displayed superior overall performance, with fewer failures observed during follow-up evaluations. Türkün

Table 1: Lists the HV-GIC products currently available on the market.

Product	Coat*	Manufacturer	Notes
-GC Fuji IX GP -GC Fuji IX GP Fast -GC Fuji IX GP Extra	G-Coat Plus (light cure 20 sec), GC Fuji Coat LC (light cure 10 sec), or GC Fuji Varnish (blow dry)	GC, Tokyo, Japan	Fuji IX GP Fast is the fast setting version of Fuji IX GP. This product achieves its initial set in only 3 minutes and 35 seconds after mixing; final finishing can begin in only 3 minutes after placement. Fuji IX GP Extra: This product contains a next generation glass filler which elicits higher translucency, fluoride release, reactivity and a faster setting time. It allows final finishing in only 2.5 minutes from initial mix.
-Riva Self Cure (Regular) -Riva Self Cure (Fast) -Riva Self Cure HV	Riva Coat (light cure resin coating)	SDI, Victoria, Australia	Riva Self Cure HV has a higher powder/liquid ratio (0.50/0.12 g) compared to the other two variants (0.42/0.12 g)
-Ketac Universal Aplicap -Ketac Molar Aplicap	Ketac Glaze (mainly for Ketac Molar Aplicap)	3M ESPE, Seefeld, Germany	Ketac Universal Aplicap is a user-friendly, versatile glass ionomer for quick, less demanding restorations, while Ketac Molar Aplicap is a tougher, packable choice for durable posterior restorations prioritizing strength over aesthetics or speed.
-Chemfil Rock	Surface protection recommended (e.g., resin-based coating or varnish)	Dentsply, Milford, USA	It uses a novel reactive zinc-modified fluoro-alumino-silicate glass filler
-Equia Fil	Equia Coat (A nanofilled, light-cured resin coating)	GC America, Alsip, IL, USA	In some markets, Equia Fil is sold as Fuji IX GP Extra and Equia Coat as G-Coat Plus.[14,25] The primary difference is that Equia Fil is Fuji IX GP EXTRA packaged within the Equia system, designed to be used with Equia Coat for enhanced properties, whereas Fuji IX GP EXTRA is the standalone GIC that doesn't require the coating.
-Gold label IX Extra Capsule -Gold label IX Extra	G-Coat Plus, GC Fuji Coat LC, or GC Fuji Varnish	GC America, Alsip, IL, USA	The Fuji IX GP EXTRA and Gold Label IX Extra are actually the exact same product — just branded differently depending on the market or region

*Although these materials can technically be used without a final coat, coating is strongly recommended to enhance wear resistance, surface hardness, and longevity.

and Kanik[33] conducted a six-year assessment of the long-term clinical efficacy of Equia Fil and Riva Self Cure (SDI, Victoria, Australia) both of which were coated with Equia Coat and a classical varnish (Fuji Varnish). Equia Fil exhibited acceptable clinical performance in class I restorations and moderate to large class II restorations over six years.

However, the clinical performance of the conventional GIC (Riva Self Cure) in moderate to large class II restorations was notably inferior to that of Equia Fil. Equia Fil demonstrated superior performance to Riva Self Cure in terms of anatomic form, color match, marginal adaptation, and retention rate throughout the evaluation period. Notably, both coatings applied to all the restorations were worn away after six months. Heck *et al.*,[32] conducted a long-term study over six years to assess the performance of two HV-GIC systems, the Fuji IX GP Fast/Fuji Coat LC and Equia Fil/Equia Coat restoration systems, which were applied as definitive restorations for class II cavities for permanent dentition. Both materials demonstrated acceptable and comparable survival rates, indicating their suitability for smaller class II cavities. Over the six years, both Equia Fil and Fuji IX GP Fast restorations showed significant deterioration in surface luster, marginal adaptation, material fracture, and retention, with no notable differences observed between the two materials. Hatirli *et al.,*[24] compared the two-year clinical outcomes of HV-GICs and nanohybrid resin composite restorations (GrandioSO, Voco). HV-GICs demonstrated comparable clinical performance to resin composite materials. HV-GICs presented lower marginal discolouration, greater surface wear and loss of anatomic form. The resin composite had a significantly better surface luster. Rożniatowski *et al.,*[31] conducted a clinical and radiological assessment comparing the Equia restorative system and resin composite material (Tetric EvoCeram, Ivoclar Vivadent). Their findings suggested that the resin composite and Equia systems exhibited similar efficacy over a 2-year observation period when used to restore approximal lesions in premolars and permanent molars. However, it is important to note that when HV-GICs were utilized, there was a greater risk of marginal adaptation deterioration, staining, and erosion. Uzel *et al.,*[27] compared the clinical performance of the Equia system on class I and II cavities with that of a bulk-fill resin composite (Tetric EvoCeram, Ivoclar, Vivadent) over 24 months in young adults. Both materials displayed good clinical performance. However, Equia showed more common chipping and surface degradation over the two years.

In summary, HV-GICs have proven to be effective restorative materials for class I and small-to-medium class II cavities, with specific materials such as Equia Fil often outperforming conventional GICs in terms of anatomic form, color match, and retention. While HV-GICs demonstrate comparable performance to resin composites in terms of retention and marginal discoloration, they face challenges in larger restorations, including marginal deterioration, surface wear, and reduced aesthetic performance. In contrast, the resin composites maintain better surface luster over time.

Glass hybrid glass ionomers

In 2015, Equia Forte (GC America, Alsip, IL, USA) was introduced as an innovative restorative system utilizing glass-hybrid technology. The system builds on the performance of the original Equia restorative line and comprises Equia Forte Fil and its corresponding light-cured surface sealant, Equia Forte Coat. Equia Forte Fil is a self-adhesive bulk-fill restorative material based on an enhanced GIC structure. It incorporates ultrafine, highly reactive fluoroaluminosilicate glass particles with a bimodal size distribution–a combination of larger conventional glass fillers and smaller, highly reactive nanofillers–improving the packing density and reactivity. These particles facilitate rapid ion release and robust matrix formation. The liquid component consists of a higher molecular weight polyacrylic acid combined with water and tartaric acid, which enhances handling and working time. Compared with traditional HV-GICs, this glass hybrid formulation results in improved ion availability, leading to enhanced cross-linking, a stronger glass-ionomer matrix, and superior flexural strength.[34] The system also includes Equia Forte Coat, a nanofilled, light-cured resin coating that contains a novel multifunctional methacrylate monomer. The manufacturer claims that this coating forms a dense, wear-resistant resin matrix that seals the surface, enhances aesthetics, and protects the restoration from early moisture contamination and dehydration.

In 2019, the Equia Forte HT (High Translucency) restorative system was launched, featuring an optimized formulation that offers improved translucency and aesthetics. Equia Forte HT maintains the same core glass hybrid structure but utilizes a refined and narrower particle size distribution, further enhancing handling properties and mechanical performance. Table 2 lists the GH-GICs products currently available on the market.

Mechanical properties

As restorative materials, GH-GICs must demonstrate adequate mechanical performance to replace missing tooth structures. Studies comparing GH-GICs to HV-GICs and resin composites have shown that GH-GICs, particularly Equia Forte and Equia Forte HT, exhibit comparable or slightly superior mechanical pro-

Table 2: GH-GICs products currently available on the market.

Product	Coat	Manufacturer	Notes
Equia Forte Fil	Equia Forte Coat	GC America, Alsip, IL, USA	
Equia Forte HT	Equia Forte Coat	GC America, Alsip, IL, USA	
Gold Label Hybrid	G-Coat Plus (light cure) or GC Fuji Varnish (blow dry)	GC America, Alsip, IL, USA	Available only in a hand mixed version

perties to HV-GICs, particularly when the Equia Forte Coat is applied.[34-40] The protective coating plays a critical role in maximizing the performance and surface durability. Fuhrmann *et al.,*[37] found that while fracture toughness was similar among GICs, the application of Equia Forte Coats significantly increased surface hardness, reaching levels comparable to those of resin composites such as Filtek Z250 and even exceeding those of Filtek Supreme Ultra. Similarly, Brkanović *et al.,*[8] reported that Equia Forte HT, both coated and uncoated, outperformed Fuji IX GP in terms of wear resistance, with coated samples showing notably greater durability.

However, despite these improvements, certain drawbacks persist. Voids may form during placement, particularly in hand-mixed versions, compromising the internal integrity of the material.[41-43] Cohesive failures have also been reported under functional loading, especially in larger restorations.[40,44] These failures highlight the intrinsic limitations in fracture toughness and fatigue resistance of GH-GICs. Notably, recent studies have consistently reported that these failures are often cohesive in nature–occurring within the material itself–while the bond to tooth structure remains intact.[45]

However, GH-GICs still lack resin composites in terms of key mechanical properties, such as compressive strength, fracture toughness, and surface hardness.[34,35,40] This is mainly due to the superior micromechanical bonding of resin composites, as well as their inherently higher material strength. Kutuk *et al.,*[46] compared Equia Forte to a microhybrid resin composite (G-ænial Posterior) and reported no significant difference in fracture resistance but significantly greater compressive strength in the resin composite. Valeri *et al.,*[47] noted that while resin composites such as Filtek Supreme Ultra showed superior wear resistance, Equia Forte HT–particularly when coated–demonstrated a substantial reduction in wear, highlighting the importance of the resin coating in enhancing clinical durability.

In addition to mechanical improvements, advancements in glass-hybrid technology have led to notable enhancements in the optical properties of GH-GICs. The introduction of Equia Forte HT marked a significant step forward in improving translucency, an essential factor for aesthetic integration with natural dentition. This improvement is attributed to the optimized particle size distribution, which allows the material to blend more harmoniously with the surrounding tooth structure. Studies comparing the optical properties of GH-GICs and resin composites have revealed mixed findings. Yeo *et al.,*[38] evaluated materials such as Equia Forte, Fuji IX, Filtek Z350, and Filtek One Bulk Fill and reported that resin composites presented significantly higher translucency levels than did GH-GICs. In contrast, Moshaverinia *et al.,*[39] found that Equia Forte HT outperformed Fuji IX and ChemFil Rock in translucency. Despite these advancements, resin composites remain the preferred choice for highly aesthetic restorations because of their superior ability to achieve high translucency and natural blending.

Resin coating

The application of a resin coating, such as Equia Forte Coat, is essential during the early maturation phase of GH-GICs.[48,49] This coating serves as a temporary barrier protecting the GIC from moisture imbalances during its initial setting phase (6 to 12 months). Resin coatings have been shown to improve surface hardness, flexural strength, surface roughness, and initial wear resistance.[48,49] Kanik *et al.,*[50] noted that resin coatings render GH-GICs wear resistant over extended durations, comparable to resin composites. Habib *et al.,*[51] found that coated GICs presented significantly greater flexural strength, reduced surface roughness, and improved marginal integrity. Fuhrmann *et al.,*[37] and Handoko *et al.,*[52] also reported significant increases in surface hardness with the application of resin coatings. Additionally, Jafarpour *et al.,*[53] demonstrated that resin coatings reduce water sorption and solubility, stabilizing the physical properties of the material.

Despite these benefits, resin coatings do not uniformly enhance all mechanical properties. For example, fracture toughness and elastic modulus remain largely unaffected, with some studies even suggesting that uncoated samples may exhibit higher elastic moduli.[37,38] Ong *et al.,*[54] concluded that the resin coating did not enhance the viscoelastic properties and was unnecessary for improving the elastic performance. Furthermore, the long-term effectiveness of resin coatings in achieving adequate wear resistance remains uncertain.[8,47,49,55]

In summary, GH-GICs, particularly Equia Forte and Equia Forte HT, represent significant advancements over traditional GICs, offering improved mechanical, optical, and biological properties. The application of resin coatings further enhances surface hardness and initial wear resistance, although their long-term effectiveness is limited. While GH-GICs outperform earlier GIC generations and are well suited for low-stress restorations, they still fall short of resin composites in key areas, such as compressive strength, fracture toughness, and translucency. However, their ease of use, cost-effectiveness, and caries-preventive properties make them valuable options for high-caries-risk patients and pediatric and geriatric populations. Future research should focus on developing more durable protective coatings and innovative formulations to increase the long-term performance of GH-GICs and bridge the gap with resin composites, expanding their role in modern restorative dentistry.

Properties of the fluoride release and remineralization of GH-GICs

GH-GICs retain the favorable biological properties of conventional GICs, including chemical bonding to the tooth structure, biocompatibility, and sustained fluoride release. Fluoride release is a hallmark of GH-GICs, offering both immediate and long-term caries prevention. The burst effect involves rapid fluoride release shortly after placement, providing an initial anticariogenic boost. This is followed by a sustained reservoir effect, where the material absorbs and rereleases fluoride over time, enhancing long-term protection.(56) The release of fluoride from GH-GICs contributes to the formation of fluorapatite, enhancing remineralization and inhibiting caries progression.(56,57) Studies indicate that Equia Forte can induce remineralization in carious dentine up to a depth of 2 mm.(58) Zebić *et al.,*(59) compared the fluoride release from three different GICs. They reported that Equia Forte released more fluoride than Fuji IX and Fuji II, which had the lowest fluoride concentration among the tested GICs. Moshaverinia *et al.,*(34) evaluated the fluoride release of three HV-GICs (Equia Forte Fil, Fuji IX, and Chemfil Rock). They reported that all the examined materials exhibited comparable initial fluoride-releasing properties, whereas Equia Forte Fil exhibited significantly greater amounts of fluoride release from the bulk of the material after 4 weeks. Similarly, another study reported that Equia Forte HT also exhibited superior fluoride-releasing capacity compared with Fuji IX GP and Chemfil Rock, further highlighting its potential role in preventing caries.(39)

However, applying a resin coating, while enhancing the mechanical properties and wear resistance of GH-GICs, presents a trade-off by reducing fluoride release. This reduction is attributed to the resin-based nature of the coating and the presence of nanofillers, which seal the microgaps in the material, thereby limiting the diffusion of fluoride ions.(60-63) As not all mechanical properties are consistently improved and the long-term benefits for wear resistance remain uncertain, the use of a resin coating should be considered selectively.(64) In clinical situations where sustained fluoride release and remineralization are important, its application may warrant careful reconsideration.(61)

Bonding to the tooth structure

Equia Forte, a GH-GIC, has demonstrated improved bond strength compared with its predecessor, Equia Fil, and other conventional HV-GICs. Studies have shown that Equia Forte has a relatively high shear bond strength (SBS) to enamel and dentin. Karadas *et al.,*(65) evaluated the SBS and adaptation at the interface between various capping materials (Biodentine), TheraCal LC, Ultrablend Plus, Calcimol LC, ApaCal ART, Ionoseal, Equia Forte and dentin. Compared with the other materials, Equia Forte presented significantly greater SBS. Despite their high viscosity, self-curing materials such as Biodentine and Equia Forte displayed superior adaptation to dentin compared with light-cured materials. Latta *et al.,*(66) reported that Equia Forte and Fuji II LC had comparable SBS and shear fatigue strength (SFS) values, both of which were significantly lower than those of the resin composite (Z100 Restorative) bonded with a universal adhesive (Prime&Bond Active). The resin composite provided superior bond durability, particularly to enamel and dentin, whereas Equia Forte and Fuji II LC showed similar clinical effectiveness in bonding to enamel and dentine.

The use of a dentin conditioner–commonly polyacrylic acid–is an optional but recommended step to increase the bond strength of GICs.(67) Research indicates that both the type of conditioner and the duration of its application can significantly impact bond strength outcomes.(68,69) Consequently, selecting the appropriate conditioner and application protocol should be tailored to the clinical situation and the desired level of adhesion.(70) In a study by Suresh *et al.,*(71) the effects of 10% polyacrylic acid and 37% phosphoric acid on permanent teeth were evaluated prior to the placement of a high-viscosity glass ionomer. The findings demonstrated that 37% phosphoric acid improved the penetration depth of the material into dentin, suggesting its potential advantage as a surface conditioner.

Equia Forte has shown favorable marginal integrity and minimal microleakage compared with conventional GICs and RMGICs. Singh *et al.,*[72] and Ali *et al.,*[73] confirmed Equia Forte's superiority over Fuji II LC and other conventional glass ionomers in reducing microleakage at the occlusal and cervical levels. A recent systematic review confirmed the suitability of Equia Forte for clinical scenarios requiring durable and reliable adhesion, particularly in cases susceptible to marginal leakage.[74]

GH-GICs reliably bond to tooth structures through chemical adhesion and micromechanical interlocking, demonstrating favorable marginal integrity and minimal microleakage. However, their bond strengths typically remain lower than those of resin composites combined with universal adhesives. This limitation should be considered during clinical decision-making, particularly in demanding adhesive scenarios.

Bonding to the resin composite

The utilization of universal bonding agents shows promise in improving the bond strength between resin composites and GH-GICs in layered restorations. Farshidfar *et al.,*[22] investigated the impact of two universal bonding agents (Clearfil Universal Bond and G-Premio Bond) on the microtensile bond strength (μTBS) of Equia Forte Fil, Riva SC, Fuji II LC, and Riva Light Cure combined with a resin composite (Kalore, GC) with or without 35% phosphoric acid. Both adhesive agents significantly enhanced the μTBS across all the materials, with RMGICs such as Fuji II LC and Riva Light Cure exhibiting higher μTBS values than Equia Forte Fil and Riva SC. Furthermore, the application of universal adhesive agents (in the etch and rinse mode) notably improved the μTBS of both conventional GICs and RMGICs to the resin composite compared with that without acid etching. In another study, Francois *et al.,*[75] explored the SBS and interface characteristics between a resin composite (Filtek Z350) and various materials, including Equia Forte Fil, Fuji IX, Fuji II LC, a bulk-fill flowable resin composite (SDR), and a regular flowable resin composite (Tetric Evo Flow), via different adhesive systems. The study concluded that the most effective bonding between the resin composite and HV-GICs was achieved via a universal adhesive in self-etch mode. Additionally, they observed intimate contact at all the interfaces examined, noting that the SBS to Equia Forte Fil varied significantly depending on the adhesive system used, with Scotchbond Universal in self-etch mode showing the highest SBS compared with the other systems.[75] Moreover, beyond enhancing interfacial adhesion, adhesives have also been reported to reinforce the underlying glass-hybrid substrate. Alqasabi *et al.,*[76] reported that these adhesive agents create a superficial laminate that increases surface hardness and reduces moisture-related degradation of GH-GICs.

However, although universal adhesives significantly enhance bonding between GH-GICs and resin composites, especially in self-etch or selective-etch modes, the bond strengths typically remain inferior to those of composite-to-composite bonding. This reflects the inherent limitations and complexity associated with layered restorations involving GH-GICs and resin composites, necessitating careful clinical consideration. Additionally, evidence regarding long-term aging effects on GH-GIC-to-composite bonding is limited, indicating the need for further investigations into durability and bond stability over time. Similarly, the potential influence of the GH-GIC layer thickness on the bond strength remains unclear and warrants future research to guide clinical protocols more effectively.

The clinical performance of GH-GICs

Several clinical studies have explored the efficacy of glass hybrid restorative systems in various clinical scenarios, including class I[25,28,30] and class II cavities.[29,77-79] A summary of these studies is presented in Table 3. GH-GICs have been established as viable choices for class I restorations[25,28,30] and small to large two-surface class II restorations.[77-79] El-Bialy *et al.,*[28] reported comparable clinical outcomes between Equia Forte Fil and Equia Fil in occlusal cavities among high-caries-risk patients after one year. Similarly, Uyumaz *et al.,*[25] demonstrated equivalent and successful clinical outcomes of Equia Forte HT coated with Equia Forte Coat compared with resin composites after one year. A long-term study comparing Equia Forte with a microfilled resin composite (Gradia Direct Posterior, GC) in class I and class II cavities over 10 years revealed comparable durability, clinical effectiveness, and maintenance of surface textures.[7]

Gurgan *et al.,*[77] evaluated Equia Forte against a microhybrid resin composite (G-ænial Posterior) in large, deep class II restorations. Despite the significant color discrepancy with glass hybrid restorations, Equia Forte exhibited a relatively high success rate after 2 years in extended class II cavities, similar to the tested resin composite. The glass hybrid restorative system showed no significant disparities in terms of retention, anatomical form, or proximal contact points. Wafaie *et al.,*[78] found that HV-GICs, including Equia Forte, performed adequately in small-to-medium class II cavities over five years but exhibited surface luster deterioration and color mismatch. Similarly, Miletic *et al.,*[79] observed comparable success between Equia Forte and a nanohybrid resin composite (Tetric EvoCeram) in moderate-to-large two-surface class II cavities at five years. However, Balkaya *et al.,*[29,80] reported superior clinical performance of resin composites over GH-GICs after one and two years, suggesting that caution should be taken in the use of GH-GICs for larger restorations. Gurses *et al.,*[81] Furthermore, HV-GICs exhibited lower clinical effectiveness than did bulk-fill resin composites in class II restorations.

Clinical evidence generally supports GH-GICs as promising alternatives under specific conditions. Indication criteria for selecting GH-GICs should consider caries risk, as these materials provide fluoride release and remineralization, making them suitable for high-caries-risk patients. The size and location of the cavity are also critical, with GH-GICs recommended primarily for class I cavities and small-to-medium-sized class II cavities where functional and esthetic demands are moderate. Additionally, these materials offer clinical convenience and are particularly beneficial in scenarios requiring rapid, straightforward placement, such as pediatric, geriatric, or medically compromised patients. Conversely, their reduced translucency and potential color mismatch limit their suitability for anterior restorations or highly visible posterior restorations. The observed performance deterioration in larger restorations and increased aesthetic demands highlight the need for clinicians to carefully balance these factors when choosing GH-GIC restorations. Further standardized long-term clinical trials are essential to clarify and refine these indications, guiding clinicians toward optimal clinical outcomes. Recognizing discrepancies in study designs, methodologies, and evaluation criteria among available studies emphasizes the need for standardized approaches to establish universally applicable clinical guidelines for GH-GIC use. A summary of the

Table 3: Summary of clinical and *in vitro* studies comparing glass HV-GICs and GH-GICs and other restorative materials.

A. Clinical studies investigating the performance and outcomes of HV-GICs and GH-GICs in class I and II restorations				
Study	**Year**	**Materials**	**Classes**	**Outcomes/Results**
Klinke *et al.,*[30]	2016	Equia system vs. Fuji IX GP Fast + Fuji Coat LC	Small to moderate class I and II	Comparable performance in class I; Equia system superior in class II restorations with fewer failures.
Türkün & Kanik[33]	2016	Equia system vs. Riva SC + Fuji Varnish	Moderate to large class I and II	Equia Fil showed better performance in class I and II restorations over 6 years; coatings wore off after 6 months.
Kharma *et al.,*[26]	2018	Equia system vs. microhybrid resin composite (Amelogen Plus)	Small class I	No statistical significance difference between both in anatomical shape, color, postoperative sensitivity, secondary caries, material handling, adaptation, and marginal staining after 9 months. Equia surface texture decreased overtime.
Balkaya *et al.,*[29]	2019	Equia Forte system, bulk-fill resin composite (Equia Forte system), microhybrid resin composite (Charisma Smart).	Small to moderate class I and II	Resin composites showed better clinical performance than Equia Forte system after 1 and 2 years.
Heck *et al.,*[32]	2020	Fuji IX GP Fast + Fuji Coat LC vs. Equia system	Small class II	Both materials showed acceptable survival rates; significant deterioration in surface luster, marginal adaptation, and retention over 6 years.

Gurgan *et al.*,[77]	2020	Equia Forte system vs. microhybrid resin composite (G-ænial Posterior)	Large class II	Equia Forte showed significant mismatch in color, both materials exhibited successful performance for the restoration of large class II cavities after 24 months.
El-Bialy *et al.*,[28]	2020	Equia Forte Fil vs. Equia Fil	Small class I	Comparable performance after 1 year in high-caries-risk patients.
Hatirli *et al.*,[24]	2021	Equia system vs. nanohybrid resin composite (GrandioSO)	Small class I	Equia system showed comparable performance to resin composite; lower marginal discolouration but greater surface wear.
Rożniatowski *et al.*,[31]	2021	Equia system vs. resin composite (Tetric EvoCeram)	Class II	Similar efficacy over 2 years; Equia had higher risk of marginal adaptation deterioration, staining and erosion.
Uzel *et al.*,[27]	2022	Equia system vs. bulk-fill resin composite (Tetric EvoCeram)	Small to moderate class I and II	Both materials showed good clinical performance; Equia had more chipping and surface degradation over 2 years.
Wafaie *et al.*,[78]	2022	Ketac Universal Aplicap, Equia Forte and Riva Self Cure HV vs. microhybrid resin composite (Filtek Z250)	Small to moderate class I and II	Although drawbacks in surface luster and color match appeared over the 5-year period, the three high-viscosity glass ionomers had successful clinical performance compared to Filtek Z250
Uyumaz *et al.*,[82]	2023	Equia Forte HT system vs. microhybrid resin composite (Charisma Smart)	Small class I	Resin composite outperform Equia Forte HT system in terms of color match and surface texture. Comparable clinical performance after 1 year.
Gurses *et al.*,[81]	2023	Two Bulk-fill Resin composites (Tetric EvoCeram Bulk-Fill and Filtek Bulk-Fill) vs. Equia Forte system.	Small to moderate class I and II	Both bulk-fill resin composites had comparable clinical performance; Equia Forte system showed lower clinical effectiveness after 2 years.
Miletić *et al.*,[79]	2024	Equia Forte system vs. nanohybrid resin composite (Tetric EvoCeram)	Small to moderate class I and II	Both materials showed satisfactory survival and success rates over 5 years.
B. *In vitro* studies investigating mechanical and physical properties of GH-GICs				
Kutuk *et al.*,[46]	2019	Equia Forte system vs. microhybrid resin composite (G-ænial Posterior)	No significant difference in fracture resistance; resin composite had higher compressive strength.	
Šalinović *et al.*,[40]	2019	Equia Forte Fil vs. Ketac Universal Aplicap vs. Equia Fil	No significant difference in compressive strength; Ketac Universal Aplicap had higher hardness values than Equia fil and Equia Forte fil.	
Moshaverinia *et al.*,[34]	2019	ChemFil Rock vs. Fuji IX GP vs. Equia Forte Fil	Equia Forte Fil had higher flexural strength and surface hardness than Fuji IX GP, with no significant difference in compressive or diametral tensile strength. Equia Forte released significantly more fluoride after 4 weeks compared to Fuji IX GP and ChemFil Rock. ChemFil Rock showed higher flexural strength (not statistically significant) but lower compressive strength and microhardness than Equia Forte Fil.	
Fuhrmann *et al.*,[37]	2020	Equia Forte vs. Ketac Universal Aplicap vs. ChemFil Rock vs. Fuji IX Extra vs. IonoStar Molar vs. resin composites (Filtek Z250 and Filtek Supreme Ultra)	The resin composite restorative materials had significantly greater fracture toughness than the glass-ionomer materials. There was no significant difference in fracture toughness between the glass-ionomer materials. Equia Forte Coat improved surface hardness but did not affect fracture toughness.	

Yeo *et al.,*[38]	2021	Filtek Z350 vs. Filtek One Bulk Fill vs. Fuji IX vs. Equia Forte	Resin composites had higher flexural strength and translucency than Equia Forte and Fuji IX. Fuji IX and Equia Forte had similar flexural strength. Coating did not enhance elastic modulus and may increase wear.
Habib *et al.,*[51]	2021	Equia Forte Fil vs. RMGIC (Fuji II LC) with and without coatings	Coating improved flexural strength, reduced surface roughness, and decreased microleakage.
Kunte *et al.,*[35]	2022	Fuji IX vs. Equia Forte Fil	Equia Forte showed slightly higher compressive and diametral tensile strength, but differences were not statistically significant.
Valeri *et al.,*[47]	2022	RMGIC (Ionolux) vs. Activa Bioactuce Restorative vs. Equia Forte HT system vs. resin composite (Filtek Supreme Ultra)	Ionolux and Activa Bioactive Restorative had comparable or less wear compared to Filtek Supreme Ultra, while Equia Forte HT wore twice as much compared to the resin composite.
Moshaverinia *et al.,*[39]	2024	Equia Forte HT vs. Fuji IX GP vs. ChemFil Rock	Equia Forte HT had improved translucency, compressive strength, flexural strength and fluoride release compared to Fuji IX. No significant difference was found in flexural strength values between Equia Forte HT and Chemfil Rock.
Abuzinadeh *et al.,*[83]	2024	Fuji IX, vs. Equia Forte vs. Fuji II vs. resin composite (Tetric-N-Ceram Bulk Fill)	Equia Forte had comparable compressive strength and microhardness to Fuji II and Fuji IX. The resin composite had the highest compressive strength and microhardness among all materials. The study results showed statistically insignificant differences in surface microhardness across all groups. Equia Forte was 40% lower microhardness values than the other materials.

included studies is presented in Table 3.

This review highlights several limitations within the literature on GH-GICs. First, there is significant variability in study designs, methodologies, evaluation criteria, and follow-up periods among clinical studies, complicating direct comparisons and generalized conclusions regarding long-term efficacy. Many existing studies have short-term follow-up periods (≤ 5 years), limiting the understanding of long-term clinical outcomes, especially concerning durability and aesthetic stability.

Additionally, the performance of the resin coatings used with GH-GICs has been inconsistently reported, with varying results in terms of long-term mechanical properties and fluoride release. This inconsistency suggests that resin coating formulations and application protocols require further refinement and standardized testing to clearly determine their long-term effectiveness.

Future research should focus on conducting long-term randomized controlled clinical trials with standardized methodologies to provide robust data on the longevity and clinical performance of GH-GIC restorations, particularly moderate-to-large posterior restorations. Studies examining long-term biological impacts, such as fluoride release and remineralization capacity in clinically relevant scenarios, are also needed. Furthermore, investigations into optimizing resin coatings, exploring new formulations, and assessing their effects on mechanical and biological properties will enhance the clinical applicability and reliability of GH-GICs. Such research directions will significantly inform clinical decision-making and expand the potential applications of these promising restorative materials.

Conclusions

GH-GICs represent a notable advancement in restorative dentistry, successfully addressing several limitations of conventional glass ionomer cements through improved mechanical performance, fluoride release, and ease of clinical application. Clinically, GH-GICs demonstrate comparable effectiveness to resin composites in class I and small to moderate class II posterior restorations. Despite these advancements, challenges remain, particularly in larger restorations, including marginal deterioration, surface wear, and limited aesthetic outcomes. While resin coatings enhance initial mechanical durability, their short-lived effectiveness and reduced fluoride release may limit long-term benefits. GH-GICs, therefore, are particularly recommended for specific patient groups, such as those with high caries risk and pediatric, geriatric, and medically compromised populations, where their biological advantages outweigh their aesthetic and mechanical limitations. Future research should prioritize long-term clinical evaluations and innovative enhancements in resin coatings to further expand the clinical applicability and durability of GH-GICs.

Conflicts of Interest

The author declare that they have no conflicts of interest.

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OSR ORAL SCIENCES REPORTS

Original Article

Regression Equations for Prediction of Permanent Canine and Premolar Mesiodistal Width in Thai Population: A Cross-sectional Study

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Abstract

Objectives: This study aimed to formulate regression equation(s) for predicting human permanent canine and premolar mesiodistal (MD) widths of Thai population.

Methods: 176 Mae Fah Luang University students with Thai nationality were selected for this study. Based on their domicile, participants were grouped by four different regions of Thailand, including central, northern, southern, and northeastern. An intraoral scanner was used to record digital dental models, and the tooth MD widths were measured using SolidWorks 2020 EP1 software. Significant differences were tested by two-sample *t*-test or one-way ANOVA. By Pearson's correlation coefficient, the relationships between the maxillary and/or mandibular incisor MD width and the upper and/or lower canine and premolar MD widths were determined for prediction equations.

Results: There were statistically significant differences in a sum of the maxillary and mandibular incisor and in that of the upper and lower canine and premolar MD widths between males and females ($p<0.001$). Statistically significant differences in the sum of the mandibular incisor MD width and in that of the maxillary and mandibular central incisor MD width were found among four different regions ($p<0.05$). By linear regression analysis, correlation coefficients of eight prediction equations were between 0.62 and 0.75 with the percentages of prediction accuracy from 47.16 to 53.41. These percentages were significantly greater than those predicted by previous models for the upper canine and premolar MD widths ($p<0.01$).

Conclusions: Our novel regression equations may predict the MD width of unerupted canine and premolars of Thai population precisely enough to be applicable for mixed dentition space analysis.

Keywords: canine, intraoral scanner, mixed dentition, premolar, regression equation, tooth size prediction

Introduction

Analysis of a mixed dentition space is a crucial step in orthodontic treatment planning. Thus, determination of mesiodistal (MD) width of unerupted canine and premolars from that of fully erupted maxillary and/or mandibular incisors is beneficial for treatment planning of orthodontists in order to select a proper treatment of choice.(1) Prediction of the MD width of the unerupted canine and premolars can be carried out by three ways: 1) a direct measurement of the unerupted teeth from dental radiographs(2), 2) an estimation from proportionality tables or prediction equations(3,4), and 3) a combination of the two methods, as aforementioned.(5) The Moyers' probability tables(3) and the Tanaka and Johnston prediction equations(4) gain popularity due to no need for dental radiography. However, both tables and equations are derived from data of Northern European populations, limiting their use in other countries. Thus, their orthodontic applications in other ethnic groups should be proceeded with caution because tooth sizes vary owing to differences from several intrinsic and extrinsic factors, such as, ethnicity, genetic, sex, and nutrition.(6) The distinction in tooth sizes among different ethnic groups of Asian populations was demonstrated in five previous studies, including 1) a study in Hong Kong Chinese;(7) 2) that in northeastern Thai population;(8) 3) that in northeastern Han Chinese;(9) 4) that in Nepalese mongoloids;(10) and 5) that in Pakistani population.(11) However, the equations obtained from these studies do not precisely predict the real MD width of canine and premolars; therefore, their clinical implications in orthodontic treatment planning are questionable.

Among the five studies, a plaster model was used to measure the tooth size. Nowadays, use of an intraoral scanner (IOS) has, however, increasingly gained popularity because it offers greater reliability and accuracy than the traditional impression.(12) Consequently, tooth size measurement from a digital dental model can yield an accuracy sufficiently to determine the MD width of permanent canine and premolars.(13) This study aimed to formulate new prediction equations for the MD width of permanent canine and premolars in a Thai population, based on the MD widths of their maxillary and/or mandibular incisors, measured from the digital dental models. Furthermore, this study was conducted in four different regions of Thailand to represent data of general Thais.

Material and Methods

Eligible participants were 14,432 university students of Mae Fah Luang University (MFU) in 2023 with Thai nationality. Of these students, a total of 238, whose domicile was from each of the four regions of Thailand, including central (n=62), northern (n=64), northeastern (n=48), or southern (n=64), were interested to enroll into this study (Figure 1). According to the sample size calculation, determined by the finite population mean formula with standard deviation at 1.36, standard error at 0.20,(8) and an alpha value at 0.05, a cohort of 176 students was required to have enough power of test. The mean age of 176 participants was 20.93 years. There were an equal number of 44 selected participants (male=22, female=22) within each region (Figure 1). The selection of 22 male and 22 female participants within each region was based on their first arrival for oral examination after enrollment with the selection criteria as follows: i) participants with all fully erupted permanent teeth, except their third molars, ii) those without tooth malformations, missing, or severe tooth crowding, iii) those without proximal caries or restorations, and iv) those without previous orthodontic treatment. An ethical approval was granted by the Human Ethics Committee of MFU, Thailand (EC 23186-22), and written informed consent was obtained. The IOS (Primscan, Dentsply Sirona, Bensheim, Germany) was used to create digital dental models.

Before actual measurements, five examiners were standardized to yield intra- and inter-examiner reliabilities, as assessed by Cohen's Kappa and Dahlberg's error, respectively. The inter-examiner standardization of MD width measurement was performed by comparisons with an experienced examiner. To test the intra-examiner reliability, the same digital dental model was randomly selected and measured twice within one week by the same examiner. The inter and intraclass correlation coefficients were 0.95 and 0.92-0.98, respectively.

Measurement of MD width

The Standard Tessellation Language files derived from the IOS were measured using SolidWorks 2020 EP1 software (Dassault Systèmes SolidWorks Corp., Bensheim, Germany). The MD width of each tooth was first determined from the mesial to the distal point of anatomical contact with the adjacent tooth, viewed at the labial or the buccal surface (Figure 2A or B). Then, the first MD width was confirmed by the greatest proximal contour of

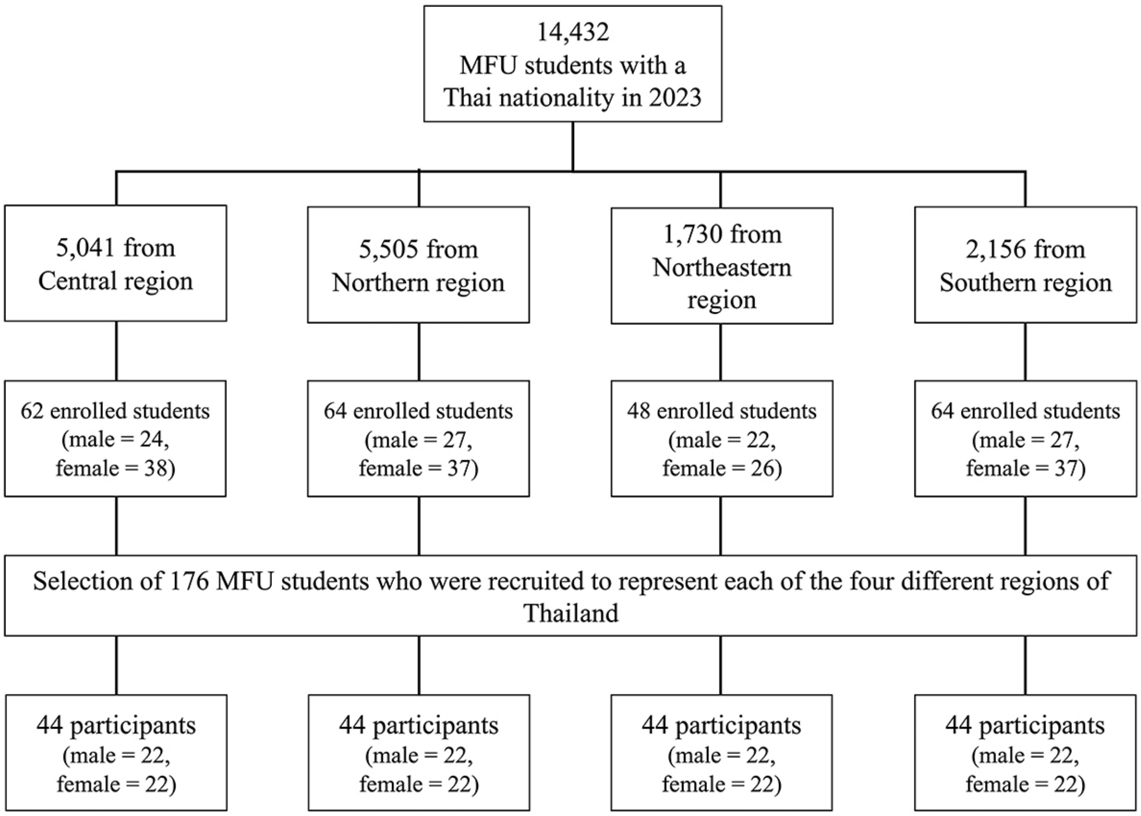

Figure 1: A flow chart of selected 176 university students of Mae Fah Luang University (MFU), recruited to represent each of the four regions of Thailand.

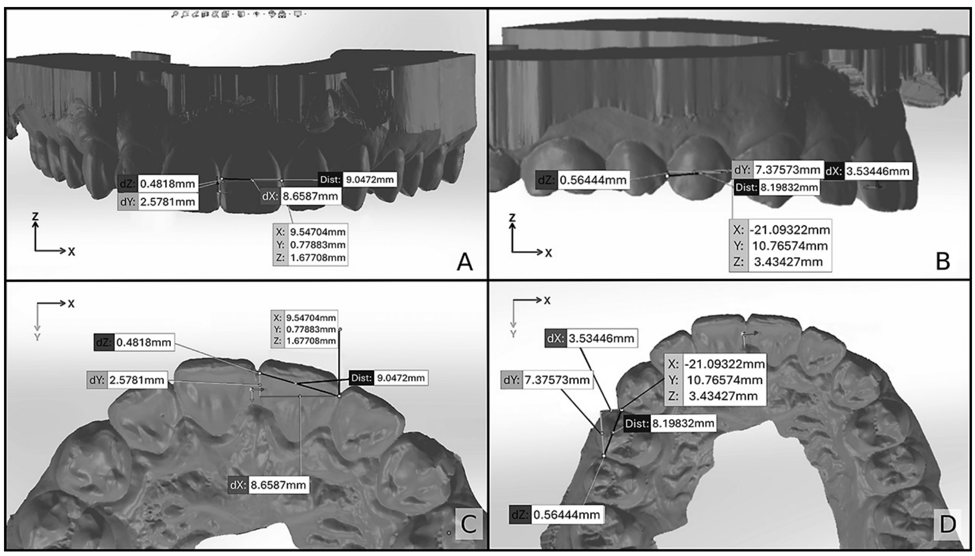

Figure 2: Representative images of a digital dental model, used in the measurement of mesiodistal width of permanent left central incisor, viewed at the labial surface (A) and the incisal edge (C). Those used in the measurement of mesiodistal width of permanent right first premolar, viewed at the buccal surface (B) and the occlusal plane (D). Numbers in the boxes indicate values on x, y, and z axes, the distance of mesiodistal width (Dist=distance), dX, dY, and dZ (Δ distance of x, y, z axes).

that tooth, viewed at the incisal edge or the occlusal plane (Figure 2C or D).

Statistical analysis

The datasets were analyzed using STATA software version 16.1 (StataCorp, TX, USA) with the confidence level at 5%. Categorical variables were described by frequencies and percentages. Based on normal distribution, continuous variables were presented with mean and standard deviation. Comparisons of MD width between sexes and among regions were analyzed by Student's *t*-test and one-way ANOVA, respectively.

Two pre-reducing models were created by generalized linear regression for sums of upper/lower canine and premolars using four predictors, including a sum of mandibular incisors, that of maxillary central incisors, that of mandibular central incisors, and that of maxillary and mandibular central incisors. The post-reducing models were created by a stepwise backward elimination method upon removal of variables (sexes, regions, or four predictors) if $p>0.05$.

The acceptable prediction accuracy of two outcomes was within ±0.5 mm. The relationships between prediction accuracy of our equations, the Moyers' probability tables, or the Tanaka and Johnston prediction equations, and an exact width of the sum of upper/lower canine and premolars, measured form digital models, were analyzed by Pearson's correlation.

Results

Comparisons of MD widths between males and females or among four regions

Male participants had significantly greater mean MD widths than females in all four predictors and two outcomes ($p<0.001$; Table 1). Of the four predictors, significant differences were found in the three predictors ($p<0.05$; Table 2). Note that the greatest mean MD widths of three predictors were found in participants from the southern region (Table 2). However, no significant differences in the mean MD width of the two outcomes were found among four different regions (Table 2).

Correlations between predictors and outcomes used to generate regression equations

Since different sexes had a significant impact on prediction of the MD widths of upper/lower canine and premolars ($p<0.001$; Tables 3 and 4, respectively), whereas distinct regions had no significant effect ($p>0.05$), the constants and coefficients of eight formulated equations were adjusted in the post-reducing model, based on the sex parameter.

The first four (Table 3) and the second four equations (Table 4) were used to predict a sum of the MD width of canine (3), first premolar (4), and second premolar (5). U=upper; L=lower; XX=female; XY=male.

1. U345=13.41-0.48(XX=1 or XY=0) + 0.44(sum of 42, 41, 31, 32)
2. U345=14.40-0.52(XX=1 or XY=0) + 0.54(sum of 11, 21)
3. U345=14.58-0.49(XX=1 or XY=0) + 0.81(sum of 41, 31)
4. U345=12.30-0.44(XX=1 or XY=0) + 0.40(sum of 41, 31, 11, 21)
5. L345=10.76-0.47(XX=1 or XY=0) + 0.51(sum of 42, 41, 31, 32)
6. L345=11.81-0.52(XX=1 or XY=0) + 0.63(sum of 11, 21)
7. L345=12.12-0.49(XX=1 or XY=0) + 0.94(sum of 41, 31)
8. L345=9.40-0.43(XX=1 or XY=0) + 0.47(sum of 41, 31, 11, 21)

Comparisons of the eight prediction equations with Moyers' probability tables and Tanaka and Johnston prediction equations

The correlation coefficients for eight prediction equations were found to be moderate to strong, or from 0.62 to 0.75 (Table 5). The percentages of prediction accuracy of the eight prediction equations, ranging from 47.16 to 53.41 (Table 5), were compared with those using the Moyers' tables and the Tanaka and Johnston equations. For the first four equations, the percentages of prediction accuracy were significantly greater than that using the Moyers' tables ($p<0.001$) and that using the Tanaka and Johnston equations ($p<0.01$; Table 5). For the second four equations, the percentages of prediction accuracy were significantly greater than that using the Moyers' tables ($p<0.05$; Table 5).

Discussion

To predict the MD widths of upper/lower canine and premolars from various combinations of the sum of the

Table 1: Comparisons of the mean mesiodistal (MD) widths of four predictors and two outcomes between Thai male and female participants. U= upper, L= lower.

	MD width	Male Mean±SD (mm)	Female Mean±SD (mm)	*p*-value
Predictors	sum of 42, 41, 31, 32	23.83±1.46	23.08±1.21	<0.001
	sum of 11, 21	17.54±1.14	17.01±0.83	<0.001
	sum of 31, 41	11.39±0.74	11.01±0.63	<0.001
	sum of 11, 21, 31, 41	28.94±1.70	28.02±1.32	<0.001
Outcomes	U345	23.82±1.08	23.02±0.91	<0.001
	L345	22.86±1.09	22.01±0.93	<0.001

Table 2: Comparisons of the mean mesiodistal (MD) widths of four predictors and two outcomes among four different regions of Thailand. U= upper, L= lower.

	MD width	Northern Mean±SD (mm)	Central Mean±SD (mm)	Northeastern Mean±SD (mm)	Southern Mean±SD (mm)	*p*-value
Predictors	sum of 42, 41, 31, 32	23.29±1.51	23.19±1.34	23.29±1.19	24.00±1.36	0.020*
	sum of 11, 21	17.05±1.17	17.24±1.02	17.24±0.95	17.52±0.93	0.185
	sum of 31, 41	11.06±0.72	11.02±0.71	11.18±0.59	11.52±0.71	0.004**
	sum of 11, 21, 31, 41	28.12±1.74	28.26±1.55	28.43±1.38	29.04±1.57	0.029*
Outcomes	U345	23.23±1.07	23.36±0.94	23.42±0.91	23.59±1.31	0.441
	L345	22.28±1.27	22.36±0.98	22.41±1.05	22.62±1.07	0.513

$^*p<0.05$; $^{**}p<0.01$

Table 3: Regression parameters for the correlation of predictor and outcome variables of upper canine and premolars (upper 3 4 5) upon pre- and post-reducing models.

	Upper 3 4 5				
	Pre-reducing model		Post-reducing model		
	Coefficient	*p*-value	Coefficient	*p*-value	Power
Sex	-0.490	<0.001	-0.480	<0.001	1
Region	0.030	0.570	-	-	-
sum of 42, 41, 31, 32	0.430	<0.001	0.440	<0.001	1
Constant	13.490	<0.001	13.410	<0.001	-
Sex	-0.530	<0.001	-0.520	<0.001	1
Region	-0.050	0.355	-	-	-
sum of 11, 21	0.530	<0.001	0.540	<0.001	1
Constant	14.510	<0.001	14.400	<0.001	-
Sex	-0.500	<0.001	-0.490	<0.001	1
Region	0.005	0.935	-	-	-
sum of 31, 41	0.810	<0.001	0.810	<0.001	1
Constant	14.600	<0.001	14.580	<0.001	-
Sex	-0.440	0.001	-0.440	0.001	1
Region	0.010	0.863	-	-	-
sum of 11, 21, 31, 41	0.400	<0.001	0.400	<0.001	1
Constant	12.330	<0.001	12.300	<0.001	-

Table 4: Regression parameters (sex and region) for the correlation of predictor and outcome variables of lower canine and premolars (lower 3 4 5) upon pre- and post-reducing models.

	Lower 3 4 5				
	Pre-reducing model		Post-reducing model		
	Coefficient	*p*-value	Coefficient	*p*-value	Power
Sex	-0.470	<0.001	-0.470	<0.001	1
Region	0.005	0.924	-	-	-
sum of 42, 41, 31, 32	0.510	<0.001	0.510	<0.001	1
Constant	10.770	<0.001	10.760	<0.001	-
Sex	-0.530	<0.001	-0.520	<0.001	1
Region	0.030	0.588	-	-	-
sum of 11, 21	0.620	<0.001	0.630	<0.001	1
Constant	11.880	<0.001	11.810	<0.001	-
Sex	-0.490	<0.001	-0.490	<0.001	1
Region	0.030	0.619	-	-	-
sum of 31, 41	0.950	<0.001	0.940	<0.001	1
Constant	12.030	<0.001	12.120	<0.001	-
Sex	-0.420	<0.001	-0.430	<0.001	1
Region	0.020	0.665	-	-	-
sum of 11, 21, 31, 41	0.470	<0.001	0.470	<0.001	1
Constant	9.320	<0.001	9.400	<0.001	-

Table 5: Comparisons of eight prediction equations with Moyer's proportionality tables and Tanaka and Johnston prediction equations. U= upper, L= lower.

		% accuracy in this study	Correlation coefficient (r)	% accuracy using Moyers	Correlation coefficient (r)	Chi-Square *p*-value (1)	% accuracy using Tanaka and Johnston	Correlation coefficient (r)	Chi-Square *p*-value (2)
U345	sum of 42, 41, 31, 32	48.30	0.66	10.91	0.55	<0.001	31.25	0.63	0.001
	sum of 11, 21	48.30	0.62			<0.001			0.001
	sum of 31, 41	47.73	0.64			<0.001			0.002
	sum of 11, 21, 31, 41	47.16	0.68			<0.001			0.002
L345	sum of 42, 41, 31, 32	53.41	0.73	38.79	0.69	0.007	51.14	0.70	0.670
	sum of 11, 21	48.30	0.69			0.017			0.920
	sum of 31, 41	51.14	0.70			0.022			1.000
	sum of 11, 21, 31, 41	51.14	0.75			0.022			1.000

p-values (1) or (2), comparisons between % accuracy in this study and that by Moyers' tables or that by Tanaka and Johnston equations, respectively.

MD widths of incisors, this study has proposed eight novel prediction equations, whose percentages were found to be significantly greater than those using Moyers' tables. The correlation coefficients for the upper canine and premolars from 0.62 to 0.68 were greater than that at 0.55 using the Moyers' tables, while those for the lower canine and premolars from 0.69 to 0.75 were comparable to that using the Moyers' tables or the Tanaka and Johnston equations. Collectively, these percentages and coefficients suggest the accuracy and reliability of our eight prediction equations be acceptable for prediction of the upper/lower permanent canine and premolar MD width of Thai population.

The Moyers' tables were developed from Northern European populations that are neither accurate nor applicable for other populations of distinct ethnic origins. The ideal correlation coefficient at 0.75, as recommended by the author,(3) is not observed in seven of the eight equations in this study (Table 5), nor is it found in another study.(14) When the Moyers' tables were applied for the Thai population in this study and in the Chinese population(7,9,15), it was found to underestimate the real MD width of upper canine and premolars that would affect orthodontic treatment planning, because more space than the predicted MD width is required for a good alignment of the erupting canine and premolars. In comparison with the Tanaka and Johnston equations, our equations were found to significantly better predict a sum of the MD width of upper canine and premolars. Note that the Tanaka and Johnston equations overestimate the mixed dentition space analysis of female Caucasians, while they underestimate the same analysis of male and female Negroids.(16) In this study, the Tanaka and Johnston equations also underestimate the mixed dentition space analysis of upper canine and premolars of Thai males and females (data not shown).

Of the eight equations, only six that did not include maxillary and mandibular lateral incisors are clinically applied in patients, whose lateral incisors are frequently afflicted by congenital missing and/or abnormal tooth size. A recent article(17) has reviewed using different predictors other than the incisors, particularly the MD width of permanent first molar. These predictors include a sum of the MD width of mandibular central incisor, lateral incisor, and first molar, and that of two mandibular central incisors and first molar. Hence, various combinations of predictors, considered to be advantageous in terms of a more diverse manner, are created. Note that the correlation coefficients of our eight prediction equations are found to be comparable to those using the combinations of the MD width of incisors and molars.(17) Nonetheless, tooth defects from dental caries or restoration involving the MD surface of permanent first molar often take place, affecting its real MD width, necessitating use of anterior teeth instead to predict the MD width of unerupted canine and premolars. In this study, sex evidently affects tooth size, by which the average size of each tooth type of males was found to be significantly larger than that of females. This finding is consistent with the previous findings in the Thai population.(8) Correspondingly, a study in the Taiwanese population(15) has shown a similar result that indicates a significantly larger tooth size in men than in women. The sex effect on tooth size could be attributed to genetic factors and sex hormones that influence tooth development.(6,18,19) Each of the four regions in Thailand differs in terms of geography, ethnicity, cultural heritage, and cuisine. Our findings indicated that regional differences had a significant effect on three of the four predictors with the greatest mean MD widths found in participants from the southern region of Thailand. These results agree with the findings from a previous study,(8) which suggest that regional differences influence tooth size. Nevertheless, regional variables, which were not found to have any significant impact in a pre-reducing model (Tables 3 and 4), were not included in the formulation of our equations in a post-reducing model, thus, making these equations simpler and more generalizable for use in the Thai population. Because of its convenience, intraoral scanning has increasingly gained popularity in orthodontic treatment nowadays.(11-13) The digitized dental images can be indirectly obtained from scanning the plaster models(11), whereas our digital dental models were derived directly from intraoral scanning. A previous study(20) has shown no significant difference between these two approaches, since an excellent agreement in the measurement of MD width obtained from either direct or indirect way was demonstrated. Thus, due to its ease, convenience, time saving, cost effective, reliability, and accuracy, intraoral scanning is recommended to directly create digital dental models. However, it is noteworthy that the measurement of MD width in this study was performed by only a specific brand of intraoral scanner; therefore, differences in the scanner accuracy, resolution, and software algorithms between the different scanners may have influenced the validity and generalizability of our findings.

Conclusions

In the Thai population, significantly larger tooth sizes in males than in females affect the prediction of upper and lower canine and premolar MD widths.

The eight MFU regression equations are precise to predict the sum of the MD width of upper/lower canine and premolars, proposing a possibility to use these equations to predict the MD width of unerupted permanent canine and premolars for orthodontic treatment planning during the mixed dentition.

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Apical Debris Extrusion of Rotary and Reciprocating Files Combined with Two Supplementary Irrigation Techniques

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Abstract

Objectives: To quantify the amount of debris extrusion after root canal instrumentation with rotary (Zenflex; ZF) and reciprocating (EdgeOne Fire; EOF) file systems combined with either Manual Dynamic Activation (MDA) or Passive Ultrasonic Irrigation (PUI).

Methods: Ninety mandibular molars with complete root formation and 10°-20° curvature were selected, disinfected, and stored. Teeth with immature apex, resorption, caries, or calcified canals were excluded. High-speed diamond burs accessed the teeth and mesial roots were used for investigation. Specimen were randomly divided into 6 groups (n=15) based on file (ZF and EOF) and irrigation systems(MDA and PUI). The apical size of prepared root canal was 25. The Myers and Montgomery method was used to collect apical debris. Debris extrusion was measured by weighing tubes pre- and post-experiment after incubating for 5 days. The mean weight differences of debris extrusion among file and irrigation system groups were compared using Two-way ANOVA with Tukey's test.

Results: The statistics showed a significant effect of irrigation technique on debris extrusion (p=0.002), while file system (p=0.698) and interaction (p=0.406) were not significant. PUI as an adjunctive irrigation with ZF and EOF (mean=0.19±0.17 and 0.19±0.14 µg respectively) significantly reduced debris extrusion compared to reciprocating EOF systems without adjunctive irrigation technique (mean=0.37±0.13 µg) (p=0.020 and p=0.017, respectively).

Conclusions: Irrigation technique significantly influenced debris extrusion, while file system had no effect. The use of PUI with both file systems reduced debris extrusion compared to EOF without adjunctive irrigation.

Keywords: apical debris extrusion, mechanical instrumentation, root canal preparation, rotary NiTi file

Introduction

Complete root canal debridement, achieved through chemical irrigants and mechanical instrumentation, is a critical step in non-surgical root canal treatment.[1,2] Chemomechanical debridement can lead to apical extrusion of debris, pulp tissue fragments, necrotic tissue, microorganism and irrigants which is one of the main causes of periapical inflammation and postoperative flare-ups.[3] Flare-ups, characterized by pain, swelling, or both, may occur within hours or days following root canal treatment and often result in unexpected interappointment emergency visits. The incidence of flare-ups during root canal treatment ranges from 1.4% to 16%.[1-3]

Despite efforts to maintain the working length short of the apical terminus across various preparation techniques and instruments, debris extrusion continues to occur in varying amounts.[2,3] Studies showed mechanical instrumentation using hand files produced more apical debris extrusion than engine-driven rotary preparation.[1,3] Moreover, push-pull filing motions generate more apical debris than rotational motions.[2]

Recently, advances in Nickel-Titanium (NiTi) rotary file technology have facilitated more effective cleaning and shaping of the root canal system. These improvements in metallurgy allow for greater preservation of tooth structure while maintaining canal anatomy. However, the literature remains inconclusive regarding the differences in apical debris extrusion between various rotary file systems. Earlier studies indicated that reciprocating file system produces more debris extrusion than continuous rotation file system[2,3], while study of Ujariya *et al.,*[4] reported inconsistent result. Recently, Kerr Corporation launched a new NiTi rotary system used in continuous motion called ZenFlex™ (Kerr Corporation, Pomona, CA, USA) which characterized by 1 mm maximum instrument diameter with the purpose to maintain more tooth structure after root canal preparation. Moreover, the manufacturer claimed of ensuring an increased cyclic fatigue and torsional resistance in comparison to other comparable instrument brands due to the proper heat treatment and the innovative design of ZenFlex™.[5]

EdgeOne Fire™ (EdgeEndo, Albuquerque, NM, USA), a recently introduced reciprocating file system, undergoes proprietary heat treatment (FireWire™) to enhance flexibility and a negligible restoring force.[6] A comparative study on the shaping ability of three reciprocating NiTi single file systems; Reciproc® blue, WaveOne® Gold and EdgeOne Fire™, in curved root canals reported that there were no statistically significant differences in the degree of canal transportation distances and preparation times among these 3 groups. The EdgeOne Fire system recorded more statistically significant percent change of canal curvature than the WaveOne® Gold system. Despite this, there are no data in literature regarding apical debris extrusion of those instruments.

The most commonly used method of smear layer removal has been the alternating irrigation with a combination of ethylenediaminetetraacetic acid (EDTA) and sodium hypochlorite (NaOCl). This combination can remove smear layer completely in the coronal and middle thirds but less effective in the apical third owing to the inability of the irrigating solutions to reach the apical third of the root canals.[7,8] For optimal effectiveness, the irrigants must contact the entire root canal surface. However, complex canal anatomy and the vapor lock effect in the apical third hinder conventional syringe irrigation from wetting the entire surface.[9]

Conventional syringe irrigation typically reaches only 1.5-2.0 mm beyond the needle tip, limiting its effectiveness to the coronal and middle thirds.[10] Therefore, intracanal agitation or activation of the irrigants is a necessary adjunction to mechanical instrumentation to remove debris and bacteria from the root canals.[11,12] Several systems for intracanal agitation of the irrigants have been proposed, which might be categorized as manual agitation devices, including the use of hand files, gutta-percha points and canal brushes, and machine-assisted agitation devices, like sonic or ultrasonic devices, rotary brushes and pressure alternation devices. Studies have shown that manual dynamic activation (MDA) using well-fitting gutta-percha master cone with gentle up and down movement in short 2- to 3-mm strokes in an instrumented canal can produce an effective hydrodynamic effect and significantly improve the displacement and exchange of any given reagent. This will result in better contact of the irrigating solution with the root canal walls, and thus enhance debridement.[13]

Studies indicated that irrigation is one of the procedures that can cause extrusion of intracanal debris into periapical[14,15] area and type of irrigation system can affect the frequency and amount of apical debris extrusion.[16] It has been known that passive ultrasonic irrigation (PUI) is more effective than conventional irrigation (CI), using syringe and needle, in eliminating pulp tissue and dentin debris.[16] PUI can remove debris and bacteria adhered on the root surface by action of acoustic streaming which produces shear stresses along the root canal wall.

To date, the effect of PUI on the apical extrusion of debris when used in conjunction with single-file systems has not been studied much. Studies evaluating the effect of MDA and PUI on the apical extrusion of debris are lacking, and therefore, this study aims to quantify the amount of debris extrusion after root canal instrumentation with rotary and reciprocating file systems combined with either MDA or PUI. The null hypothesis (H_0) is that there is no significant difference in the amount of debris extrusion among different combinations of ZF and EOF file systems with either MDA or PUI.

Materials and Methods

This study was approved by the Human Experimentation Committee, Faculty of Dentistry, Chiang Mai University, Thailand (NO.18/2023).

2.1 Sample size

Sample size was calculated by adopting an alpha (α) level of 0.05, beta (β) level of 0.20 i.e., power = 80%, effect size (f) = 0.4. The calculation based on results of Gummadi *et al.,*[16] using G*power version 3.1.9.7 (Heinrich Heine University, Düsseldorf, Germany) revealed the total sample size is 90 samples.

2.2 Sample selection

Ninety mandibular molars (except mandibular third molar) were collected and stored in normal saline. The included teeth had complete root formation with root curvature approximately 10º-20º measured by Schneider method.[17] Calculus and debris were removed with ultrasonic scaling and disinfected with 5.25% NaOCl for 10 minutes then stored in normal saline until used. Periapical radiographs in mesiodistal and buccolingual views had been taken to verify apical foramen and root canal configuration. Only teeth which mesial root had type II or IV Vertucci's configuration were included in this study. Teeth with immature apex, root resorption, root caries, and calcified canal were excluded.

2.3 Experimental model design

The mesiobuccal canal of mesial root was used in our study. Each specimen was created by the following procedure. High-speed diamond burs were used to access the teeth and to separate the distal and mesial roots. In the mesial roots, the canals were checked for apical patency with K-file no.10 (Densply Sirona, Ballaigues, Switzerland). The length of each canal was established by inserting no.10 K-file into canal space until the tip of file was visible at apical foramen, then subtract 1 mm. The final working length of mesiobuccal canal was 16 mm and adjusted by flattening the cusp tip, then confirmed with a radiograph. A K-file no.15 inserted until the working length was reached and teeth which had a passive fit at the working length were selected. Teeth were divided randomly into 6 groups based on the file system and the irrigation system (n=15).

2.4 Specimen preparation and debris collection model

The model and process for collecting apical debris extrusion was adopted from Myers and Montgomery method (Figure 1).[18] Double layer of cyanoacrylate used to cover the external surface of all roots except for 1 mm from root apex. Each empty Eppendorf tubes were numbered and weighed without the lids by 5-digit analytical balance (Shimadzu, Kyoto, Japan). Pre-experimental weight of tube (W1) was the mean value of weighting each empty tube for 3 times.

Micromotor used to make a hole on the lid of the tube then mesial roots were inserted into the hole and fixed with cyanoacrylate. To keep the balance of air pressure inside and outside of the tubes, a 27-guage needle was inserted in to the lid. The lid was attached back to the tube and the whole apparatus was concealed in a glass bottle with putty, the glass bottle was then covered with black tape to prevent the operator from seeing through while doing the instrumentation process.

The samples were allocated using a random group allocation online software (http://www.randomizer.org) into six groups of fifteen teeth according to the file system (Zenflex and EdgeOne Fire) and the irrigation systems (PUI and MDA) (n=15) used.

2.5 Root canal preparation and irrigation

The mechanical Instrumentation procedures were performed using X-smart Plus motor (Densply Maillefer, Ballaigues, Switzerland). The instrument flutes were cleaned with sterile gauze after 3 passes. The canal was irrigated with 2 ml of distilled water using using a 30G

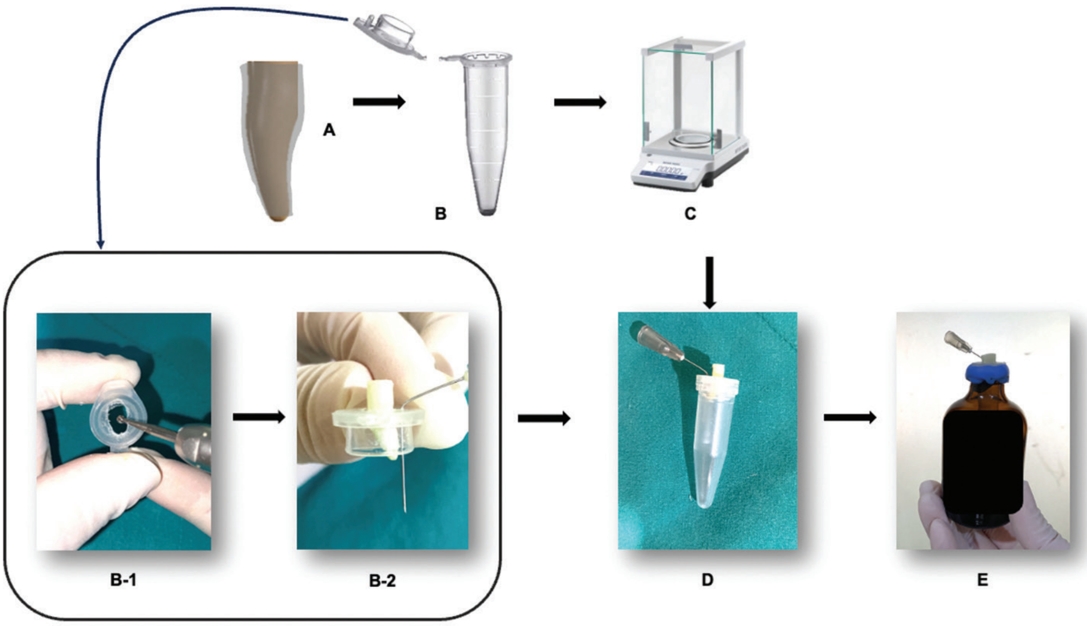

Figure 1: Schematic illustration of the debris collection model modified from Myers and Montgomery (1991).[18] (A), Cyanoacrylate (nail polish) was applied 1 mm above the root apex to seal the apical foramen: (B), The lid of an Eppendorf tube was removed: (B-1), A hole was drilled in the lid to fit each sample, and the sample was sealed in place with cyanoacrylate: (B-2), The sample was inserted up to the mid-root level, and a needle was inserted through the lid to equalize pressure: (C), The Eppendorf tube was weighed without the lid: (D), The prepared lid was securely placed back onto the tube: (E), The tube was fixed to a glass bottle using putty, and the bottle was covered with tape to prevent contamination.

needle with a syringe and size 10 K-file was used to maintain apical patency. These procedures were repeated until the file reached the WL. Total volume of irrigant was limited to 8 ml per tooth.

Group 1: ZF – without adjunctive irrigation

Zenflex™ rotary file size 20 taper 06 to 25 taper 06 were used according to the manufacturer's instruction with a rotational speed of 500 rpm and torque of 2 Ncm. The conventional irrigation using a 30G needle with a syringe with normal saline solution was performed.

Group 2: EOF – without adjunctive irrigation

EdgeOne Fire™ file size 25 taper 07 was used according to the manufacturer's instruction with a 350 rpm speed in 170° CCW and 50° CW direction and completes 360° in 3 cycles.[19] The canal was irrigated in the same manner as in Group 1.

Group 3: ZF + MDA

Zenflex™ rotary file size 20 taper 06 to 25 taper 06 were used, followed by irrigating with MDA technique. With a gentle up and down movement of a gutta percha master cone size 25 taper 04 with the WL-1mm in short 2- to 3-mm strokes with the frequency approximately 100 times per minute (~1.6 Hz) was done.

Group 4: EOF + MDA

EdgeOne Fire™ file size 25 taper 07 was used, followed by irrigating with MDA technique in the same protocol as in Group 3.

Group 5: ZF + PUI

Zenflex™ rotary file size 20 taper 06 to 25 taper 06 were used, followed by PUI technique. An irrisafe with tip size 20 (Satelec Acteon, Merignac, France) was activated at 2 mm short of working length for 1 minute after preparation of canal via Newtron P5® ultrasonic device (Satelec Acteon, Merignac, France) with level 6 of power setting folowing the manufacturer's instruction.

Group 6: EOF + PUI

EdgeOne Fire™ file size 25 taper 07 was used, followed by PUI technique as described in Group 5.

Each rotary file was used for a maximum of four canals and cleaned between uses with sterile gauze, ultrasonic bath (1 min), and microscopic inspection to ensure no debris remained. Instrumentation and irrigation were performed by one operator, while an independent examiner (blinded to the groups) assessed debris extrusion.

2.6 Debris collection and measurement

Following instrumentation, the root was removed from the lid, and any residual debris was rinsed into the Eppendorf tube using 1 mL of distilled water. The tubes were then incubated at 70°C for 5 days to evaporate moisture before weighing the extruded debris. The post-experimental weight (W2) was recorded as the average of three measurements. Debris extrusion was calculated as: (W2-W1).

2.7 Statistical analysis

All the graphs, calculations, and statistical analyzes were performed using GraphPad Prism software version 10.4.1 for MacOS (GraphPad Software, San Diego, CA, USA). The difference of mean weight of extruded debris among all groups were examined using two-way analysis of variance (ANOVA) with Tukey's post hoc test in order to investigate the main effect of each factor (file system and irrigation technique) and interaction effect of both factors on apical debris extrusion. The level of significance was set at $p<0.05$.

Results

The mean ± standard deviation (SD) of apical debris extrusion for each experimental group, along with the results of the two-way ANOVA analysis were demonstrated in Table 1. The analysis revealed a significant main effect of irrigation technique ($F(2,84)=6.965$, $p=0.002$), indicating that the irrigation method significantly influenced the amount of debris extrusion. However, the main effect of file system was not significant ($F(1,84)=0.152$, $p=0.698$), suggesting that the type of file system did not independently affect debris extrusion. Additionally, the interaction effect between file system and irrigation technique was not statistically significant ($F(2,84)=0.911$, $p=0.406$), indicating that the influence of irrigation technique on debris extrusion remained consistent regardless of the file system used.

As illustrated in Figure 2, post hoc multiple comparisons using Tukey's test showed that debris extrusion was significantly lower in groups of both files which PUI was added as an adjunctive irrigation method (Group 5 and 6; mean=0.19±0.17 and 0.19±0.14 µg respectively) ($p=0.020$ and $p=0.017$, respectively) than using EOF file only (Group 2; mean = 0.37±0.13 µg). The combination of PUI regardless of file system (Group 5 and 6) tended to produce less debris extrusion than those groups using MDA technique (Group 3 and 4; 0.28±0.15 and 0.24±0.15 µg respectively) although the statistical significance could not be observed. Furthermore, ZF without supplemental irrigation (Group 1; mean=0.30±0.12 µg) did not exhibit a statistically significant difference in debris extrusion compared to other groups.

Discussion

Apical debris extrusion produced by root canal treatment during mechanical instrumentation and irrigation could caused postoperative flare-ups, inflammation, and delayed periapical healing.[20,21] Previous studies have demonstrated that increased debris extrusion is associated with greater inflammatory mediator release, such as prostaglandins and substance P, which contribute to postoperative discomfort.[22,23] Additionally, residual extruded debris may harbor bacterial biofilms, increasing the risk of persistent apical periodontitis.[24]

In this study, the mesiobuccal canals of mandibular

Table 1: Mean ± SD of debris extrusion (µg) for different file systems and irrigation techniques. Two-way ANOVA results are reported, showing the effects of file system (rotary vs. reciprocating), irrigation technique (w/o irrigation, MDA, PUI), and their interaction. $p<0.05$ is considered statistically significant (**). Abbreviations: w/o = without irrigation, MDA = Manual Dynamic Agitation, PUI = Passive Ultrasonic Irrigation.

File system	Irrigation technique	Mean ± SD	Two-way ANOVA (*p*-value)
ZF	w/o adjunctive	0.30±0.12	File system: 0.698
	MDA	0.28±0.17	Irrigation technique: 0.002 **
	PUI	0.19±0.17	Interaction: 0.406
EOF	w/o adjunctive	0.37±0.13	
	MDA	0.25±0.15	
	PUI	0.19±0.16	

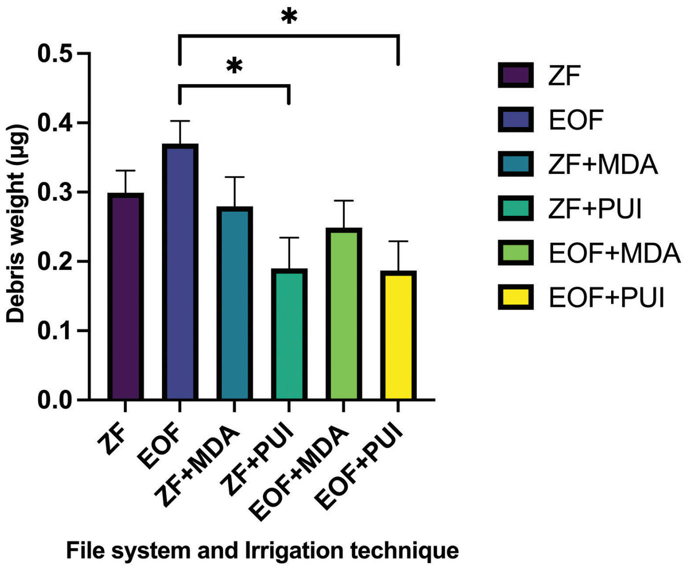

Figure 2: Mean debris extrusion (µg) for different file systems and irrigation techniques. ZF = Zenflex; EOF = EdgeOne Fire; MDA = Manual Dynamic Agitation; PUI = Passive Ultrasonic Irrigation. Error bars represent standard of error (SE). Asterisks (*) indicate statistically significant differences (p<0.05, Tukey's post hoc test).

molars were selected due to their relevance in clinical scenarios where curved canals are commonly found in multirooted posterior teeth. Moreover, curved and complex canals were one of the factors that affected the treatment outcome and the amount of apical debris extrusion.(25) The materials and methods of this study was modified from the study of Myers and Montgomery(18), which was the mainly method used to study the amount of apical debris extrusion after mechanical instrumentation and irrigation. Distilled water was used as the irrigant instead of NaOCl to prevent crystallization and contamination of the debris with sodium crystals.(16,21,26)

The present study evaluated the effects of different file systems (rotary vs. reciprocating) and irrigation techniques (without adjuctive irrigation, MDA, and PUI) on debris extrusion. Two-way ANOVA revealed that irrigation technique had a significant effect on debris extrusion (p=0.002), whereas file system (p=0.698) and the interaction between the two factors (p=0.406) were not significant. These findings suggest that irrigation strategy plays a more critical role in debris extrusion than the choice of file system.

The significant effect of irrigation technique aligns with previous studies demonstrating that PUI significantly reduces apical debris extrusion compared to conventional irrigation methods.(27) The enhanced debris removal with PUI is attributed to its ability to induce acoustic streaming and cavitation, effectively dislodging debris and minimizing its apical extrusion.(28) Additionally, the oscillating motion of the ultrasonic file promotes lateral flow of irrigant along the root canal walls, preventing debris accumulation at the apex.(29) Our post hoc analysis demonstrated that both rotary (ZF) and reciprocating (EOF) file groups using PUI (Group 5 and 6) extruded significantly less debris compared to the EOF without adjuctive irrigation method (Group 2). These findings support the combining PUI as an adjunctive root canal irrigation to optimize debris removal(16) and minimize the risk of postoperative complications associated with extruded debris.(30,31)

In contrast, although no significant differences were observed, the MDA technique tended to produce relatively more debris than PUI when combined with the same file system (Group 3 vs. Group 5 and Group 4 vs. Group 6). This may be attributed to the up-and-down movement of the gutta-percha cone in MDA, which may generate unstable hydraulic forces and push debris beyond the apex. Furthermore, variability in the pumping force applied manually by the examiner may contribute to inconsistent debris extrusion.

Interestingly, the type of file system did not significantly influence debris extrusion. Our results showed that ZF without adjunctive irrigation (Group 1) did not exhibit a significant difference in debris extrusion compared to any other groups. Although mean debris extrusion in Group 1 was lower than that in EOF without adjunctive irrigation (Group 2), this difference did not reach statistical significance (Figure 2). These findings suggest that, while different file kinematics may influence debris extrusion, the effect may not be as substantial as the irrigation technique, which demonstrated a significant impact. The absence of a significant difference between Group 1 and the MDA or PUI groups further reinforces the dominant role of irrigation dynamics over file motion in controlling debris extrusion. This contradicts previous reports suggesting that reciprocating systems generate more extruded debris due to their cutting dynamics and lack of continuous withdrawal motion.(2,3,16) The discrepancies between studies may occur from differences in tooth type, working length, apical diameter, and file size.

The absence of a significant interaction effect between file system and irrigation technique suggests that the beneficial effect of PUI is independent of the instrumentation technique used. This reinforces the idea that irrigation technique exerts a stronger influence on debris extrusion than file kinematics, supporting the prioritization of effective irrigation strategies in clinical practice.

In clinical situation, although there is no study at the present that demonstrate the certain amount of extruded debris that can cause the postoperative complications. While the observed reduction in apical debris extrusion of approximately 0.1 micrograms may seem minor, its clinical significance should not be underestimated. A literature review emphasized that any irritation to periapical tissues, including minimal debris extrusion, may result in flare-ups and impede healing.(22) Therefore, even a small reduction in debris extrusion could potentially decrease the risk of postoperative complications, thereby enhancing patient comfort and treatment success.

A limitation of this study is that the experimental model does not fully replicate the clinical periapical structure, as it lacks the apical resistance typically provided by bone or periapical tissue.(22) Additionally, there were different microhardness of dentin between samples which could affect the difficulty of the instruments while cutting dentin.(32) Future studies could improve upon these limitations by developing more realistic models, such as using gel to mimic an apical barrier or employing micro-CT to collect debris.(26) Further research could also focus on clinical outcomes, such as the incidence of postoperative pain following the use of ZenFlex and EdgeOne Fire combined with MDA and PUI.

Conclusions

With the limitations of the study, our data found that irrigation technique significantly influenced apical debris extrusion, while file system motions had no effect. PUI significantly reduced debris extrusion compared to reciprocating EOF systems without adjunctive irrigation technique. The absence of an interaction effect suggests that irrigation plays a more critical role than instrumentation motion.

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Conflicts of Interest

The authors declare no conflict of interest.

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Original Article

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Shear Bond Strength, Tie-wing Fracture Resistance, and Frictional Resistance of a Custommade Ceramic Bracket Version 1

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Abstract

Objectives: Shear bond strength (SBS), tie-wing fracture resistance (Tie-wing FR), and frictional resistance of a custom-made ceramic orthodontic bracket version 1 (CC bracket v1) were evaluated.

Methods: CC bracket v1 and its mould were designed by incorporating average buccal surface-curvature of Thai premolars into its base and fabricated by injection-moulding technique. SBS, Tie-wing FR and static frictional resistance of CC bracket v1 were compared to those of a commercial ceramic bracket (N=10). Normally distributed data were compared between groups using t tests.

Results: SBS means were significantly different between CC bracket v1 and controls (17.25±5.63 MPa and 24.75±5.29 MPa, respectively, $p < 0.05$). Tie-wing FR was significantly lower for CC bracket v1 (41.74±5.34 MPa) than the controls (89.48±15.93). Frictional resistance was significantly greater for CC bracket v1 (141.93±35 gf) vs. controls (86.83±25.4 gf).

Conclusions: CC bracket v1 exhibited lower SBS and Tie-wing FR but clinically acceptable. However, its frictional resistance needs improvement.

Keywords: bracket base, ceramic bracket, fracture resistance, frictional resistance, shear bond strength

Introduction

Concerning in aesthetics has led to an increase in the development of aesthetic orthodontic appliances. The curvature of the base of ceramic orthodontic brackets is generally designed to conform to tooth anatomy. Commercial ceramic brackets mostly have the base curvature conformed to Caucasian tooth surfaces. If they are used in different population, it can result in unprecise direction of forces exerting on the tooth.(1) Thonggerd *et al.,*(2) reported that the average buccal surface curvature of the upper premolars of Thai individuals was less curved than the surface curvature of a commercial bracket base, for which the mean difference reached 0.07558 mm. (Figure 1). The authors described that the occluso-gingival curvature of the tooth differed more than the mesio-distal aspect, which suggested that this difference could affect the precision of torque and rotational movement even though the bracket was bonded in the correct position. In addition, when the bracket base did not conform to the tooth surface, it could result in un-uniform thickness of adhesive at the tooth-bracket base interface which could be a cause of bond failure.(3) Using digital surface scanning technology, a custom-made ceramic bracket can be designed by incorporating the average tooth curvature of specific samples into the bracket base. This should improve the precision of tooth movement and reduce the adhesive thickness, which may result in better interfacial shear bond strength between the tooth and the bracket base.

To address this issue, an initial version of a custom-made aluminium oxide ceramic orthodontic bracket was designed and developed by incorporating mean curvature of buccal surface of upper premolars, derived from Thai samples, into the bracket base.(4) Continuing to the previous study(4), version one of the custom-made ceramic bracket (CC bracket v1) was developed by altering its design while maintaining the curvature of the bracket base as our previous study.(4)

The CC bracket v1 was improved to prevent bracket-wing fracture during fabrication process. It was designed to have more round corners without sharp angles in order to obtain better stress distribution when disengaging its mould during fabrication. To achieve an optimal bond strength, the mechanical retention at the bracket base was increased by adding irregularly shaped aluminium oxide ceramic crystals to the bracket base.

The bracket was made of polycrystalline aluminium oxide ceramic material previously developed by Wasanapiarnpong *et al.,*(5) which offered appropriate mechanical properties for ceramic brackets, including high fracture toughness, transparency, and biocompatibility.

The CC bracket v1 was fabricated using injection-moulding technique and sintering process. A mould of the CC bracket v1 (Figure 2) was developed by an engineering team at the Thai-German Institute of Technology using a reverse engineering process. To enhance the success rate of fabrication and prevent fracture of the bracket wings during disengagement of the mould pieces, a custom-made mould was designed. This stainless steel mould also accounted for 25% shrinkage of the ceramic material during the sintering process.(4) This study extended the benefits of surface-scanning technology to develop custom-made ceramic orthodontic brackets for use in individuals or specific populations in the future.

Adequate bond strength to tooth surface, high fracture toughness of the tie-wings of the brackets, and low frictional resistance to the wires are considered basic mechanical requirements of the orthodontic ceramic brackets. The objectives of this study were to compare the mechanical properties of CC bracket v1 and a commercial ceramic bracket in terms of shear bond strength (SBS), tie-wing fracture resistance (Tie-wing FR), and static-frictional resistance (S-FR).

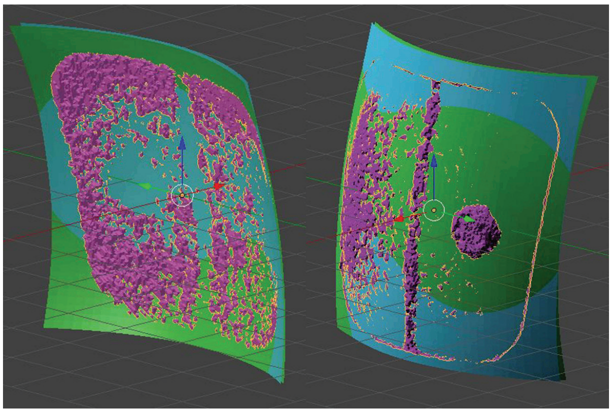

Figure 1: The difference between the average curvature of the buccal surface of the upper premolars of samples from Thai individuals (blue) and curvature of the commercial bracket base (green and purple). Purple represents the rugged curvature of the real base in the commercial ceramic bracket, whereas green represents a commercial bracket's curvature in a fit curve pattern closely resembling the ultimate curvature of the purple.

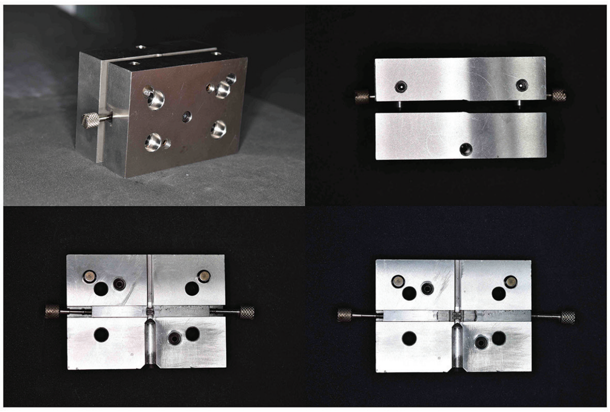

Figure 2: The metal mould of CC bracket v1. There are two separating compartments with handles that can be pulled apart to prevent ceramic bracket fracture during fabrication.

Materials and Methods

Fabrication of the custom-made ceramic bracket version 1

The material composition of the CC bracket v1 consisted of magnesium aluminium oxide ($MgAl_2O_4$), polyethylene glycol (PEG), polyvinylbutyral, and stearic acid. These components were mixed in two cycles and compressed using an injection-moulding technique to obtain the desired shape. The process began by injecting lubricating oil into the mould, which was heated to 200 degrees Celsius. The mixture was then injected into the mould at a temperature of 210 degrees Celsius. The mould was cooled to room temperature, and the brackets were carefully removed from the mould. The brackets were soaked in distilled water for 24 hours to dissolve the remaining PEG.

To enhance the retention property of the bracket base, a mixture of 100-300 nm $MgAl_2O_4$ powder and ethanol at a 50:50 ratio by weight was prepared. The mixture was applied to the base of the bracket using a fine-tip brush under a 10X magnifying scale loupe. After allowing the ethanol to completely evaporate, the bracket was heated at approximately 500 degrees Celsius for one hour to remove the remaining binders. The temperature was raised to 1,650 degrees Celsius at a rate of 5 degrees Celsius per minute and maintained for 2 hours before allowing the bracket to cool naturally in an electric furnace. Then, the bracket was removed from the electric furnace, and the external surfaces were polished with a superfine diamond bur.

Mechanical properties

Shear bond strength test

The SBS test was performed according to Thonggerd *et al.,*[(4)] and Suliman *et al.,*[(6)] This research was approved by the University Human Ethics Committee (SWUEC-384/2564X). Twenty unidentified upper premolars were anonymously collected from a hospital and dental clinics and were kept in accordance with the standards of ISO 3696:1987. Inclusion criteria of the samples was a sound tooth with a definite cemento-enamel junction. The exclusion criteria for sample collection were enamel cracks, any signs of caries, abfraction, abrasion, an enamel craze line, enamel hypoplasia, demineralization, or fillings on the crown or root.[(7)]

The tooth samples were prepared by mounting the root in 1×1×1 $inch^3$ dental die stone blocks that were allowed to set completely in a humidified box.

The samples were randomly divided into 2 groups (10 teeth per group). Group 1 included CC brackets v1, and Group 2 served as the control group (a commercial ceramic brackets with 022" slot; Clarity Advanced™, 3M Unitek, Monrovia, USA). The tooth surfaces were polished, etched with 37% phosphoric acid (3M Unitek) for 30 seconds[(4)], and air-blown until a chalky white appearance was revealed. The primer was applied (Transbond XT™, 3M Unitek, Monrovia, USA) on the tooth surface and air-thinned for 10 seconds. An adhesive bonding agent (Transbond XT™, 3M Unitek, Monrovia, USA) was applied to the tooth surfaces and at the bases of the brackets. The brackets were positioned on the tooth surfaces in the middle of the crown in occluso-gingival and mesio-distal dimensions. The brackets were placed with a hand instrument and pressed with 5 N force, which was measured using a force gauge. The excess adhesive was removed, and the adhesive was cured with LED light (Mini-LED Satelec, Acteon, Mount Laurel, USA) for 20 seconds on each side.[(4)] After bonding, the specimens were stored in 37°C distilled water[(4,6)] for 24 hours before testing.

The specimens were fixed on a stand of a universal testing machine (EZ test, Shimadzu, Japan), and the level of the bracket's wing was aligned parallel to the direction of the applied force and knife-edge blade of the testing machine (Figure 3). The SBS was tested at a cross-head speed of 1 mm per minute[(4)] until the bonding between the bracket and the tooth surface was broken. The failure load was recorded and reported as megapascals by dividing the failure load value by the surface area of the bracket base. After the SBS test, all specimens were evaluated using the adhesive remnant index (ARI)[8] obtained using optical microscopy at a magnification of 20. The failure load and ARI score were statistically analysed.

ARI index was categorized into 0-3 scores, as follows:

- 0, no adhesive left on tooth
- 1, less half of the adhesive left on the tooth
- 2, more than half of the adhesive left on the tooth
- 3, all the adhesive left on tooth with mechanical pattern visible[8]

Tie-wing fracture resistance test

Tie-wing FR was tested using methods adopted from Thonggerd *et al.,*[4] and Johnson *et al.,*[9] Ten samples from Group 1 (CC bracket v1) and Group 2 (controls) were tested and compared.

Each bracket was fixed on acrylic blocks with resin adhesive (Transbond XT™, 3M Unitek) (Figure 4A) and attached to a platform of the testing machine. The ceramic bracket was held with a 0.012-inch ligature wire at the horizontal slot (Figure 4B). The retention of specimens was enhanced by embedding the gingival part of the bracket into the acrylic resin (Figure 4C). Disto-incisal wing of the bracket was tied with a 0.012-inch ligature wire, and both ends were attached to the loading part of the universal testing machine (Figure 4D). The Tie-wing FR was measured in tensile mode at a cross - head speed of 10 mm per minute until the bracket wings fractured (Figure 4E). The tensile force value was recorded in Newtons and converted to megapascal by dividing the failure load value by the contact area between the ligature wire and the tie-wings.

Frictional resistance test

The static frictional resistance (S-FR) test was modified from Jian-Hong Yu *et al.,*[10] and Tribumrungsuk *et al.*[11] Ten samples from Group 1 (CC bracket v1) and Group 2 (controls) were tested. The S-FR between the slot surface of the ceramic bracket and the 7 cm length of 0.019”×0.025” stainless steel wire was recorded with a universal testing machine.

Each ceramic bracket was fixed on a metal plate, positioned at a mark point and a jig to ensure that the wire and the bracket slot were parallel to each other with 0-degree torque, and then ligated with an elastomeric ring (3M Unitek). The upper end of a 0.019”×0.025” stainless steel wire was attached to the upper compartment of the testing machine (Figure 5).

After the specimen was prepared, the machine pulled the wire through the bracket slot using a 50 N load cell and a crosshead speed of 2 mm per minute. The frictional force–displacement curve was plotted, and the peak of the static frictional force was recorded and statistically evaluated.

Scanning electron microscopy (SEM)

The bracket surface was attached to the sample base and coated with gold. The surface of each bracket was analysed using SEM (JSM, 6480LV, JEOL™) to investigate the grain size, shape, homogeneity of the $MgAl_2O_4$ crystals, and the bracket surface roughness.

Data analysis

Statistical analysis was performed using SPSS version 27.0 (SPSS Inc., Chicago, Illinois, USA). Shapiro–Wilk test results showed that the data were normally distributed, differences between the two groups were analysed using the independent t test. The chi-square test was used to compare the ARIs of each group. The statistical significance level was set at $p<0.05$.

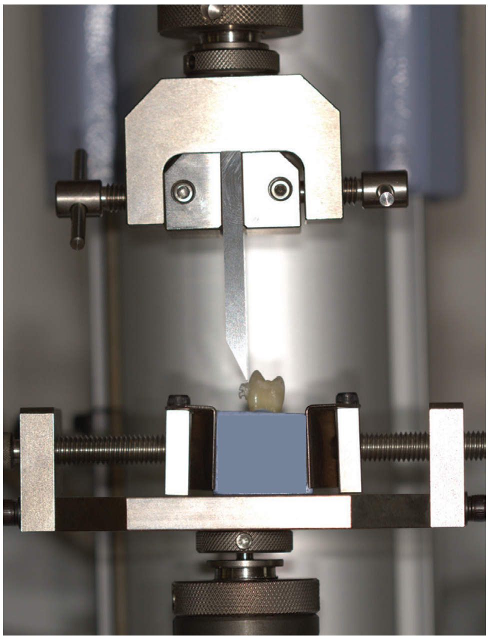

Figure 3: The shear bond strength test was performed using a universal testing machine (EZ test, Shimadzu, Japan) at a cross - head speed of 1 mm per minute.

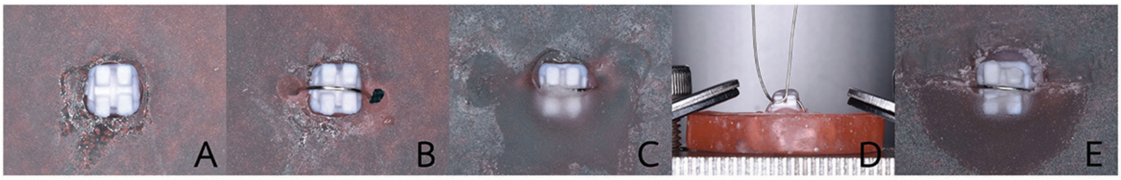

Figure 4: The specimen preparation process (A-C) and the Tie-wing fracture resistance test using a universal testing machine (D and E) (EZ test, Shimadzu, Japan).

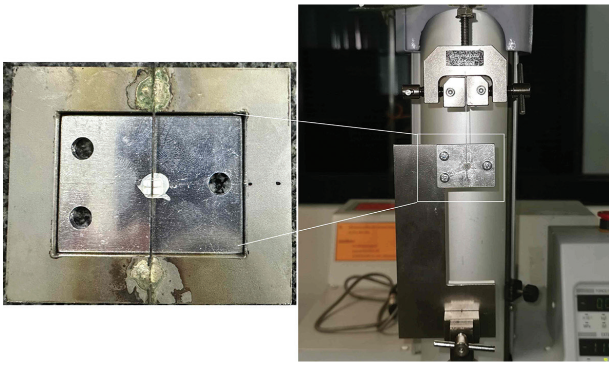

Figure 5: Frictional resistance was tested using the universal testing machine (EZ test, Shimadzu, Japan).

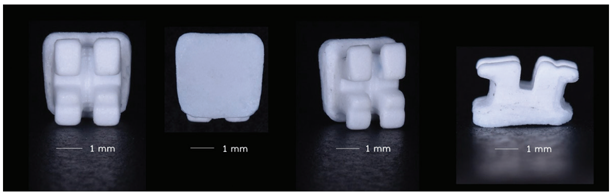

Figure 6: The custom-made ceramic bracket version 1.

Results

Fabrication of the custom-made ceramic bracket version 1

The CC bracket v1 showed no excess ceramic beneath the tie-wing area, and the horizontal slot size was appropriate for a 0.019”×0.025” stainless steel wire (Figure 6).

Mechanical properties

Shear bond strength and ARI tests

The SBS means of Group 1 (CC bracket v1) and Group 2 (controls) were 17.25±5.63 MPa and 24.75±5.29 MPa, respectively. Statistical analysis indicated a significant difference ($p<0.01$) in the SBS between the two groups (Table 1). Group 2 showed patterns of debonding with ARI scores ranging from 1 to 3, whereas the ARIs of Group 1 ranged from 2 to 3. A score of 3 was the most frequently observed in Group 1. Statistical analysis indicated no significant difference in the ARI scores between the two groups ($p>0.05$) (Table 2).

Tie-wing fracture resistance

The means of the Tie-wing FR of Group 1 (CC bracket v1) and Group 2 (controls) were 41.74±5.34 MPa and 89.48 ± 15.93 MPa, respectively. Statistical analysis indicated a significant difference ($p<0.001$) in Tie-wing FR between the two groups (Table 3).

Static frictional resistance

The mean S-FR of Group 1 (CC bracket v1) was 141.94±35 gm, whereas Group 2 (controls) had a mean S-FR of 86.83±25.4 gm. Statistical analysis revealed a significant difference ($p<0.001$) in the static frictional resistance between the two groups (Table 4).

Scanning electron microscopy (SEM)

SEM evaluation revealed that the crystals at the base of the commercial ceramic bracket were larger in size than the $MgAl_2O_4$ crystals found on the base of CC bracket v1 (Figure7). SEM analysis of the surface roughness revealed that the commercial ceramic bracket had grain sizes mostly less than 10 µm, whereas CC bracket v1 had grain sizes exceeding 50 µm (Figure 8).

Discussion

Fabrication of the custom-made ceramic bracket version 1

Digital technology can be applied to the manufacturing of orthodontic appliances. This study aimed to incorporate scanning surface technology to design a custom-made ceramic bracket with a base that has anatomical curvature conforming to a group sample from a specific population. The injection mould used to produce the custom-made ceramic bracket was constructed using reverse engineering and 3D printing of stainless steel. The ceramic injection and sintering processes used to fabricate the

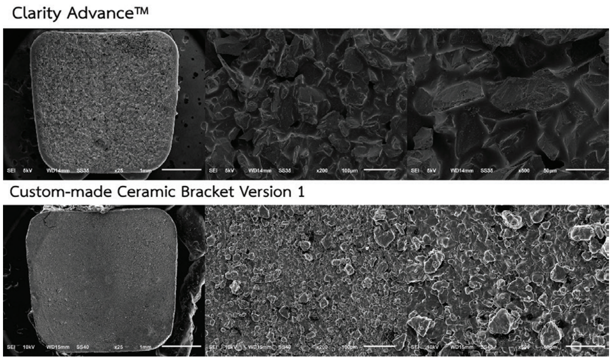

Figure 7: Surface of bracket base of the commercial ceramic bracket and the CC bracket v1 in magnification of 25×, 200× and 500×. The crystals at the base of the Clarity bracket were larger in size compared to the $MgAl_2O_4$ crystals found on the CC bracket base.

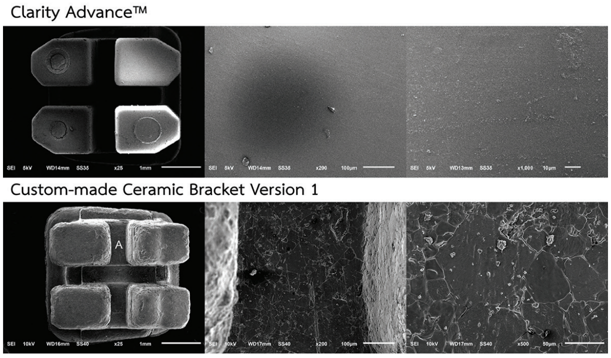

Figure 8: Surface roughness of the commercial ceramic bracket and the CC bracket v1 (Bracket slot; A) at 25×, 200× and 500× magnification.

Table 1: Comparison of the SBS means between CC bracket v1 and the controls (Clarity Advance™).

	Cross section area of bracket base (mm^2)	Mean SBS (MPa)	Range (MPa)	*p*-value
Group 1 (CC bracket v1)	12.8	17.25±5.63	7.51-26.86	.008**
Group 2 (Controls: Clarity Advance™)	11.69	24.75±5.29	18.14-31.33	

**$p<0.01$, independent *t*-test

Table 2: Comparison of the ARI scores between CC bracket v1 and the controls (Clarity Advance™).

ARI score	0	1	2	3	*p*-value
Group 1 (CC bracket v1)	0%	0%	25%	75%	.074
Group 2 (Controls: Clarity Advance™)	0%	37.5%	37.5%	25%	

*$p>0.05$, Chi square *t*-test

Table 3: Comparison of mean tie-wing fracture resistance between the CC bracket v1 and the controls (Clarity Advance™).

	Mean fracture resistance (N)	Area of touched wire (mm^2)	Mean fracture resistance (MPa)	Range (MPa)	*p*-value
Group 1 (CC bracket v1)	16.69±2.17	0.4	41.74±5.34	32.1-51.86	.000***
Group 2 (Control: Clarity Advance)	35.79±6.38	0.4	89.48±15.93	68.73-115.05	

***$p<0.001$, Independent *t*-test

Table 4: Showed comparison of means static frictional resistance between the CC bracket v1 and the controls (Clarity Advance™).

	Mean of Frictional Resistance (gm)	Range (gm)	*p*-value
Group 1 (CC bracket v1)	141.94±35	92.05–189.36	.000***
Group 2 (Controls: Clarity Advance™)	86.83±25.4	54.15–148.34	

***$p<0.001$, Independence *t*-test

custom-made bracket can be performed in an in-house laboratory. This study showed the potential benefits of digital technology for the fabrication of custom-made ceramic brackets for individuals in the future.

A limitation of this study is the absence of a validated method to accurately assess whether the curvature of the base conforms to the mould, which should be addressed in future research.

Shear bond strength

Adequate shear bond strength between the bracket base and tooth surface is pivotal for the delivery of effective forces in orthodontic treatment. A higher SBS is not always favourable; on the other hand, an optimal bond strength is preferred to prevent premature loss of the brackets as well as to prevent enamel loss in the debonding process.(6) According to a study by Reynold(12), the minimum SBS required for successful clinical orthodontic bonding was 5.88-7.85 MPa. Zepperi *et al.,*(13) reported that the clinically acceptable SBS ranged from 13 to 21 MPa. The results of this study showed that the average SBS of CC bracket v1 was greater than the minimum clinically acceptable SBS reported by Reynold(12) and within the clinically acceptable range reported by Zepperi *et al.*(13)

The debonding pattern revealed by the ARI index analysis indicated that the debonding stress of CC bracket v1 was concentrated at the interface between the bracket base and adhesive material (ARI-2, ARI-3). In contrast, given the higher SBS in the Clarity Advance group, the debonding stress was equally concentrated at the bracket base–adhesive interface (ARI-2=37.5%) and enamel–adhesive interface (ARI-1=37.5%), which could increase the risk of enamel damage during bracket debonding. According to Retief *et al.,*(14) 13.5 MPa was the minimum bond strength at which enamel damage could occur during the debonding process. This study showed that the average SBS of the Clarity Advance was greater than 13.5 MPa, so bond failure at the enamel–adhesive interface was frequently observed, indicating good bonding to enamel but a greater risk of enamel loss. Although there was no statistically significant difference in the ARI values between the two groups, ARI-3 was the most frequently observed in the CC bracket v1 group (ARI-3= 75%). These findings suggested that the CC bracket v1 could contribute to a lower risk of enamel damage during debonding but still had a clinically acceptable SBS.

The shear bond strength between ceramic bracket and enamel can be affected by many factors, including the pattern and size of the bracket base.(15-17) A previous study(4) suggested that the irregularity and consistency of $MgAl_2O_4$ crystals at the bracket base might affect the bond strength. SEM analysis revealed that the crystal particles at the base of CC bracket v1 were irregular in shape. Large crystals at the CC bracket v1 base provided extensive undercuts or irregularities on the surface. These undercuts offered additional surface area for the adhesive resin to mechanically interlock and form a stronger bond with the tooth surface, leading to optimum SBS. Studies of ceramic bracket base designs(15-16) reported that a bracket with 50 μ-round glass particles incorporated onto its alumina base showed the highest SBS of 24.7±1.9 MPa. The results suggested that these beads had adequate undercuts for mechanical interlocking of the adhesive resin, which could increase the bonding ability. Based on the SEM study (Figure 7), the crystals at the base of the Clarity bracket were larger in size than the $MgAl_2O_4$ crystals found on the base of the CC bracket v1. Specifically, the average size of the crystals in the Clarity bracket base was within the range of 20 to 100 μm, whereas the average size of the crystals in the CC bracket v1 base was less than 25 μm. Therefore, discrepancies in the crystal sizes could be a factor involved in the lower SBS observed in CC bracket v1. The next version of the CC bracket base might be improved by increasing the size of the $MgAl_2O_4$ crystals to create more undercuts for mechanical retention and to enhance the optimal SBS of the bracket.

A study by Newman(17) reported that a larger bracket base led to increased bond strength. The size of the bracket base of CC bracket v1 was 12.8 mm^2, which was larger than the size of the Clarity Advance bracket (11.69 mm^2). However, the results of this study did not correspond to those of the study by Newman.(17) Thus, the irregularity of the crystalline grains of ceramic materials at the bracket base might have a greater effect on SBS than the surface area of the bracket base.

Apart from shear bond strength, dissimilarity of the occluso-gingival aspect of the curvature between the commercial ceramic bracket base and the buccal surface of the upper premolars of Thai individuals could impact torque and rotational movement.(2) Nevertheless, effects of differences between various types of bracket base including that of the CC bracket v1 and the anatomical surface of a tooth on torque and rotational movements should be further investigated in future studies.

Tie-wing fracture resistance

Ceramic bracket fractures are associated with material property of aluminium oxide to withstand multiple direct forces. Resistance to breakage additionally relies on the specific type, shape, grain size, overall volume, and quality of the manufacturing process of the ceramic brackets.[18-27]

Sharp outlines and pointed angles at the corner of the ceramic brackets could increase stress at the concentrating area of the torque and tip when a controlled force is applied.[9,18,19] Fractures usually occur at the tie wings and the inner slot[19]; thus, the bracket design of the tie wings and the inner slot is important for improving the fracture toughness of ceramic brackets.[19,20] CC bracket v1 was designed to have round corners and few sharp angles. However, the average tie-wing fracture resistance of CC bracket v1 was significantly less than that of the control group (41.74±5.34 and 89.48±15.93, respectively, $p<0.001$). Although this bracket design did not improve the Tie-wing FR, it could still withstand the fabrication process by preventing bracket wing fractures during disengagement from the mould.

Another important factor for the fracture resistance of a ceramic bracket is the grain size of the ceramic material. Larger grain sizes, especially those exceeding 5 µm, tend to reduce ceramic strength.[21-23] According to the SEM study, the commercial ceramic bracket was composed of grain sizes less than 10 µm, whereas the CC bracket v1 was composed of materials with grain sizes that exceeded 50 µm. This significant difference in grain size could contribute to the lower tie-wing fracture resistance of CC bracket v1 compared to that of the controls.

The fracture toughness of the bracket wing could be influenced by the thickness of the ceramic material. According to the critical load equation, the critical load varied with the square of the ceramic layer thickness[24-25], meaning that the strength of the bracket wing was affected by its dimensions. The wing of the CC bracket v1 was 0.2 mm thinner than that of the controls in all three dimensions. This difference in thickness could result in a reduced fracture resistance of the tie-wing of CC bracket v1. However, to our knowledge, no previous study has quantified an impact of different thickness on tie-wing fracture resistance. Therefore, it is suggested for future investigation.

Defects, such as voids and microcracks, occur during the custom manufacturing process[18,26], contributing to a reduction in the fracture resistance of CC bracket v1.[24,26-27] SEM analysis revealed the presence of pores in CC bracket v1, which could result in a lower tie-wing fracture resistance than that of commercial ceramic brackets.

When considering the ligating force to a bracket, the average Tie-wing FR of the CC bracket v1 (16.69±2.17 N) was still greater than the average elastomeric ligation force (3.6-5.3 N) reported by Nakhaei *et al.*[28] For the development of future versions of the CC bracket, in addition to the reduction of porosity, it might be necessary to decrease the grain size and increase the size of the wings.

Frictional resistance

Previous studies reported that the frictional resistance of ceramic brackets was greater than that of stainless-steel brackets. The frictional resistance of the slot of the bracket was caused by the high coefficient of friction of the ceramic material and increased by the rough surface condition.[29] To our knowledge, no study has reported clinically acceptable frictional resistance for fixed orthodontic brackets. Compared to previous studies[30-33] in which the frictional resistance of polycrystalline ceramic brackets (0.022”× 0.028”-slot) was tested with 0.019”×0.025” stainless steel wire and ligated with a clear elastomeric ring, the average static frictional resistance of CC bracket v1 (141.93±35 gf) was greater than that of Clarity Advance, 3M Unitek™ (86.83±25.4 gf), Signature, RMO™ (114.1±22.8 gf)[31] and Reflection, Ortho Technology™ (118.6±52.5 gf)[32] but less than that of Transcend series 6000, 3M Unitek™ (152.5±53.6 gf)[33] and Illusion plus, Ortho Organizers™ (230.45±0.21 gf).[30] The average frictional value of the CC bracket v1 was found to be the closest to those of the Transcend series 6000, 3M Unitek™. SEM revealed that the surface of CC bracket v1 exhibited greater irregularity than that of the controls, which is consistent with the findings of a previous study.[19] However, higher frictional resistance of the CC bracket v1 may affect the efficiency of tooth movement, further studies should be investigated in the future.

The manufacturer of the Clarity Advance reported that its bracket slot was coated with yttria-stabilized zirconia to reduce friction. In addition, a study reported that coating a slot with a silica layer could also reduce the frictional resistance.(34) These techniques can be used to improve the frictional resistance of CC bracket v1 in the future.

Conclusions

1. The CC bracket v1 was designed to incorporate the average curvature of the upper premolars of the Thai population onto the bracket base. It can be fabricated in an in-house laboratory using the injection-moulding technique and sintering.

2. The SBS of the CC bracket v1 was lower than that of the controls but clinically acceptable.

3. Although the Tie-wing FR of the CC bracket v1 was less than that of the controls, it was greater than the elastic ligature tying force to the bracket wings.

4. The frictional resistance of CC bracket v1 was greater than that of the controls but comparable to that of other commercial ceramic brackets.

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Evaluation of Microtensile Bond Strength Between Biodentine and Post Cement at Different Time Intervals

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Abstract

Objectives: To investigate the microtensile bond strength (µTBS) of various adhesive systems (etch & rinse, self-etch, and self-adhesive) for bonding MultiCore Flow and Biodentine at different time intervals.

Methods: Sixty pairs of 7x7x3 mm resin-based 3D-printed blocks with a 1x1 mm central tube were used in this study. One side of the blocks was filled with Biodentine, while another side was filled with MultiCore Flow. The materials were bonded using one type selected from these adhesive systems: ExciTE F DSC (etch & rinse), Multilink N (self-etch), or RelyX U200 (self-adhesive). Each group was subdivided into immediate and delayed groups (n=10). Specimens were subjected to µTBS testing, and failure modes were observed under a stereomicroscope. Two-way ANOVA was used to analyze the influence of time and adhesive system on µTBS.

Results: The results revealed that Multilink N group showed significantly higher µTBS in the immediate group compared to the delayed group (p=0.01). When comparing the materials, ExciTE F DSC performed significantly worse than Multilink N (p=0.02) and RelyX U200 (p=0.04) in the immediate group. The predominant failure modes observed under the stereomicroscope were mixed failure and cohesive failure within Biodentine.

Conclusions: Immediate placement of adhesives and MultiCore Flow over Biodentine showed higher microtensile bond strength than delayed placement. Overall, self-adhesive systems demonstrated high bond strength at both time intervals. Immediate bonding with self-adhesive systems may enhance the bond strength between Biodentine and MultiCore Flow in clinical practice, potentially leading to improved restoration longevity and reduced risk of failure.

Keywords: biodentine, cement, failure mode, microtensile bond strength, post

Introduction

Root canal treated teeth often have a significant loss of structural integrity. Consequently, after root canal treatment, it becomes necessary to place a post within the root canal as part of the restorative process. The primary purpose of a post is to serve as a retention for the core build-up material.[1] Additionally, a well-placed post contributes to a more intimate seal between the restorative material and the root canal. Studies conducted by Ray & Trope in 1995[2] and Tronstad *et al.,* in 2000[3] have demonstrated that the quality of root canal filling and restoration directly influences the long-term success rate of the treated tooth. Root canal filling materials, such as gutta-percha with sealer, are typically used in simple root canal treatment cases. However, more complex cases, including open apices and perforations, may require alternative materials. Hydraulic calcium silicate-based cements like Biodentine (Septodont, St. Maur-des-Fossés, France) have emerged as promising options for these situations. Biodentine possesses chemical and physical properties that make it an ideal material for root canal repair. It also demonstrates a short setting time and strong adhesive properties to dentin, making it a suitable restorative material for dentin.[4,5] Case reports have documented the successful use of Biodentine for apexification in a single visit, replacing the traditionally used MTA (mineral trioxide aggregate; Dentsply Tulsa Dental, Tulsa, OK, USA), which has a longer setting time.[6,7] Furthermore, a study by Yadaw *et al.,* in 2020[8] evaluated the single-visit obturation of necrotic immature permanent teeth with Biodentine and reported a 100% success rate at a 9-month follow-up.

Following endodontic procedures, resin composite core materials, MultiCore Flow (Ivoclar Vivadent, Schaan, Liechtenstein), are commonly used for post placement and core build-up. When placing a post within a root canal, an interface is created between two materials: hydraulic calcium silicate cement and post cement. Various adhesive systems are commonly used to bond these two surfaces. Contemporary adhesive systems include etch-and-rinse system such as ExciTE F DSC (Ivoclar Vivadent) and OptiBond FL (Kerr Corporation, Brea, CA, USA), self-etch system such as Multilink N (Ivoclar Vivadent) and Panavia V5 (Kuraray Noritake Dental Inc., Tokyo, Japan), and self-adhesive system such as RelyX U200 (3M ESPE, Deutschland GmbH, Neuss, Germany) and G-Cem Link-Ace (GC Corporation, Tokyo, Japan). These adhesive systems have been widely used as post cements in clinical practice.

Posts placed within root canals typically have a snug fit, limiting lateral movement. Therefore, the primary forces experienced by the restoration are vertical. These vertical forces, akin to tensile strength, may lead to debonding at the interface between Biodentine and post cement. Additionally, the setting reaction between Biodentine and the adhesive system may influence bond strength. Moreover, the material's stiffness can affect bond strength. Some studies have examined bond strength between Biodentine and adhesive systems, such as the study by Hardan *et al.,*[9] which found that both self-etch and total-etch strategies exhibited promising bonding performance with Biodentine. However, there is a lack of study on the microtensile bond strength of these materials, which should be elucidated. Therefore, this study addresses this gap by using standardized 3D-printed blocks to compare the microtensile bond strength of three different adhesive systems to Biodentine.

This study aimed to investigate the microtensile bond strength (μTBS) between Biodentine and MultiCore Flow using various types of adhesive systems at different time intervals.

Material and Methods

Sample size calculations was determined from a similar study using this formula (Figure 1).[10,11] With α level type I error at 0.05 and β level type II error of 0.20 for the study, a sample size of 10 were obtained for each group.

$$n/gr = \frac{2(Z_\alpha + Z_\beta)^2 \sigma^2}{(\mu_1 - \mu_2)^2}$$

Figure 1: The formula of calculating sample size.

Sixty sets of 3D-printed clear resin blocks (120 pieces of blocks and 60 pieces of covers) were meticulously designed using Google SketchUp 2020 software (Google LLC., Mountain View, CA) and printed using a 3D Printer called Pro 55 (SprintRay, Los Angeles, CA), with surgical guide resin, which utilized DLP processing. The transparency of the resin blocks facilitates complete light transmission, ensuring full curing and polymerization of the material. The manufacturer's guidelines were followed to ensure precision and consistency in the fabrication process.

The block was designed with 7x7x3 mm^3 in size. These blocks featured a central tube with dimensions of 1x1 mm^2, extending along the length of the block. When paired, the central tubes from each block interconnected to form a continuous 14 mm long tube. To minimize material leaking, small gaps were incorporated between the “connecting end” of the blocks. The opposite end, referred to as the “application end”, served as the entry point for introducing material into the block.

The cover was designed to prevent movement and stabilize a pair of blocks. It is 18x11x3 mm^3 in size. The cover had a 2-millimeter reinforcement on the edges of its width and length for added strength, while the base of the cover is 1-mm thick. The internal size with a dimension of 14x7x2 mm^3 were specifically tailored to accommodate the blocks securely. This would cause the blocks to protrude approximately 1 mm above the cover. The cover also featured a 3 mm^2 opening at each end, corresponding to the dimensions of the opening in the central tube of the blocks for material application. Additionally, a 3 mm^2 opening was located at the center of the base for observation during experiments and easy removal of the blocks (Figure 2).

Prior to use, each block was undergone thorough cleaning and subjected to an additional round of ultrasonic cleaning to ensure optimal sterility and cleanliness, thus maintaining the integrity of the experiment, and minimizing potential contamination. Then, the blocks were paired within the cover, with the connecting ends aligned towards each other. The connecting ends were ensured to fit snugly within the cover, forming a perfectly interconnected tube.

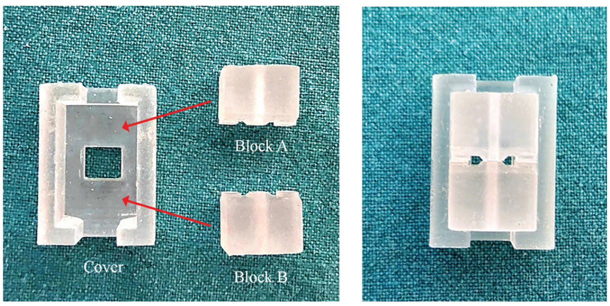

Figure 2: 3D-printed resin block and cover. (Left) Disassembled components, with arrows indicating the insertion of Block A and Block B into the cover. (Right) Assembled unit, showing the cover stabilizing and aligning the blocks for specimen preparation and testing.

The 60 sets of blocks were equally divided into three groups based on the adhesive system used: ExciTE F DSC (Etch & rinse), Multilink N (Self-etch), and RelyX U200 (Self-adhesive). Each group was further subdivided into two subgroups according to the timing of adhesive material placement on Biodentine. In the immediate group, blocks were paired with MultiCore Flow immediately after Biodentine's initial setting (approximately 12 minutes). In the delayed group, blocks were paired with MultiCore Flow after a full 14-day Biodentine setting period.

Biodentine was carefully inserted into each individual block within a set. An endodontic plugger (RCP5/7; Hu-Friedy, Chicago, IL, USA) was used to compress the Biodentine within each block to a consistent thickness of approximately 2 mm. Finally, the paired resin blocks were combined to form the complete set.

Different adhesive systems were applied to Biodentine's interface according to their respective groups: ExciTE F DSC (etch-and-rinse), Multilink N (self-etch), and RelyX U200 (self-adhesive). For each adhesive system, the surface of the resin block was prepared according to the manufacturer's recommended protocol. MultiCore Flow was then applied to achieve a uniform 2-mm thickness to the prepared hole of the other resin block. This prepared block was then connected to the Biodentine block at the varying time intervals described earlier. Subsequently, the MultiCore Flow was light-cured through the resin block using Bluephase N® LED light-curing unit (Ivoclar Vivadent) at HIGH-mode for 20 seconds to ensure complete polymerization at the interface. Subsequently, the samples were incubated at 37°C and 99% humidity for 7 days before undergoing the µTBS test.

After a 7-day incubation, the prepared 3D-printed resin blocks were securely attached to the brass gripped testing fixtures using cyanoacrylate adhesive (Loctite 416; Henkel Corp. Connecticut, USA) to establish a firm connection for testing, The cover was removed prior to the test. Subsequently, µTBS was assessed using an Instron® 5566 universal testing machine (Instron Engineering Corporation, Norwood, MA, USA) at a crosshead speed of 1 mm per minute (Figure 3). The maximum force at failure was recorded in Newtons (N) and the µTBS values were calculated in megapascals (MPa; newton/mm^2) by dividing this force by the cross-sectional area of the bonded region (1 mm^2).

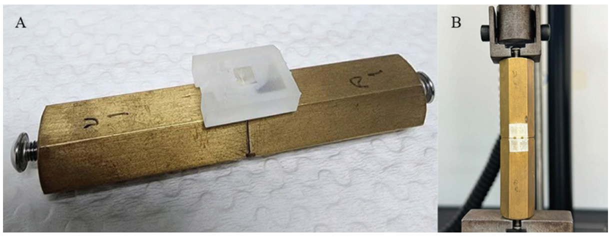

Figure 3: Specimen preparation and µTBS testing. (A), A 3D-printed resin block set (with bonded Biodentine and MultiCore Flow) was attached to the brass testing fixture using cyanoacrylate adhesive: (B), After attachment, the cover was removed, and the specimen was mounted in the universal testing machine for µTBS measurement.

The fractured surfaces of specimens were examined under a 40x stereoscopic microscope (Olympus Corp. Tokyo, Japan) to analyze and categorize into four types of failure modes according to the following criteria:

- Adhesive failure: This occurs entirely between the layers of Biodentine and MultiCore Flow.
- Cohesive failure in Biodentine: This occurs entirely in Biodentine.
- Cohesive failure in MultiCore Flow: This occurs entirely in MultiCore Flow
- Mixed failure: This involves fractures both in Biodentine and MultiCore Flow, as well as between the layers of Biodentine and MultiCore Flow.

The results were presented as mean ± standard deviation (SD) and were subjected to statistical analysis using SPSS 25.0 software (SPSS Inc, Chicago, IL, USA). The µTBS values were assessed for normal distribution using the Shapiro-Wilk test. A two-way analysis of variance (ANOVA) was conducted to assess the presence of significant differences in µTBS values between the groups.

Results

The microtensile bond strength testing

In the immediate group, Multilink N showed the highest µTBS values (18.81±6.61 MPa) compared to RelyX U200 (17.95±4.13 MPa) and ExciTE F DSC (10.66±4.07 MPa). However, in the delayed group, Multilink N showed the lowest µTBS values (6.95±3.76 MPa) compared to ExciTE F DSC (8.39±1.60 MPa) and RelyX U200 (12.26±6.34 MPa).

Within each material group, the delayed subgroups consistently showed lower µTBS values than the immediate subgroups. However, statistical analysis revealed a significant time-dependent effect only in the Multilink N group (*p*=0.01). Moreover, when comparing material groups, ExciTE F DSC revealed significantly worse than Multilink N (*p*=0.02) and U200 (*p*=0.04) in the immediate group. On the contrary, no significant differences were observed among the materials in the delayed group (*p*>0.05) (Figure 4).

Failure mode distribution

The most common failure modes observed were mixed failures and cohesive failures in the Biodentine in

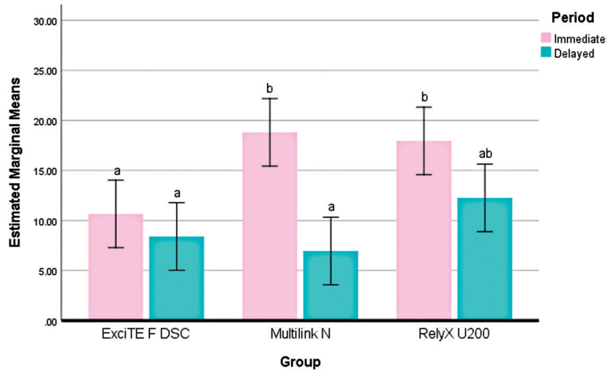

Figure 4: The bar graph of microtensile bond strength by groups (n=10/group). Same letter means no statistically significant difference and different letters means statistically significant difference among the experimental groups.

Table 1: Comparison of microtensile bond strength between different adhesives at different sealer application times.

Group (MPa)	Immediate	Delay
Multilink N	18.81±6.61	6.95±3.76
RelyX U200	17.95±4.13	12.26±6.34
ExciTE F DSC	10.66±4.07	8.39±1.60

Table 2: Effect sizes (Cohen's d) comparing microtensile bond strength between immediate and delayed groups for each adhesive.

Adhesive system	Multilink N	RelyX U200	ExciTE F DSC
Effect size	0.74	0.47	0.34

Table 3: effect sizes (Cohen's d) comparing microtensile bond strength between adhesives at immediate and delayed time points.

Adhesive Comparison	Immediate	Delay
Multilink N/RelyX U200	0.16	1.02
Multilink N/ExciTE F DSC	1.48	0.50
RelyX U200/ExciTE F DSC	1.78	0.84

Table 4: Percentages of failure modes among experimental groups.

Groups	Types of failure (%)	Adhesive	Cohesive in Biodentine	Cohesive in MultiCore Flow	Mixed failure
ExciTE F DSC	Immediate	20	30	10	40
	Delayed	10	40	0	50
Multilink N	Immediate	20	40	0	40
	Delayed	30	30	0	40
RelyX U200	Immediate	0	50	0	50
	Delayed	10	30	0	60

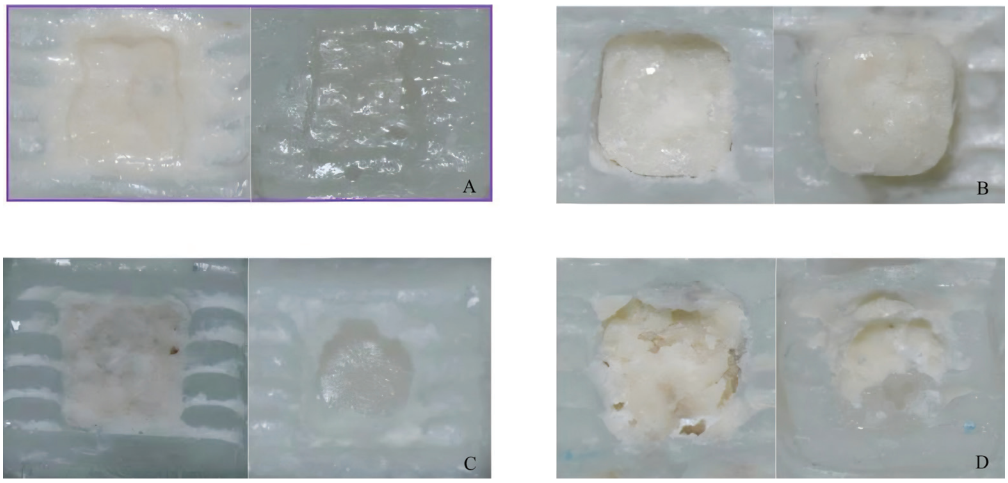

Figure 5: Representative images of the different failure modes observed after microtensile bond strength testing. (A), Adhesive failure at the Biodentine-MultiCore Flow interface: (B), Cohesive failure within the Biodentine material: (C), Cohesive failure within the MultiCore Flow material: (D), Mixed failure.

all experimental groups (Table 4). The different characteristics of failure modes observed are shown in Figure 5.

Discussion

Microtensile bond strength test is a widely used method to evaluate the bond strength between composite materials and dentin. It has also been applied to assess the bond strength between acrylic teeth and denture bases.[12] In this research, we modified the µTBS technique for a novel application in the field of endodontics, specifically focusing on bond strength between endodontic materials like Biodentine and MultiCore Flow with different adhesive systems. This model allows for a standardized and quantitative evaluation of bond strength used in endodontics. The results of this study will contribute to the development and optimization of bonding protocols for endodontic ceramic materials.

In this study, customized 3D-printed resin blocks were developed with a block and cover system aimed at reducing bias. However, further validation is required to confirm their efficacy and reproducibility. Despite the implementation of meticulous protocols, the potential for operational errors to impact on the findings cannot be eliminated. Moreover, µTBS testing may not fully represent clinical performance due to the complexities of the oral environment. Future investigations could benefit from exploring alternative methods, such as tensile tests, which are generally less sensitive and may provide more reliable results.

The observed differences in bond strength between adhesive systems can be attributed to their varying interaction mechanisms with Biodentine. This study found that the etch-and-rinse system, ExciTE F DSC, exhibited lower immediate bond strength, suggesting that acid-etching may not create optimal surface conditions for micro-retention on Biodentine's surface, potentially due to differences in its microstructure compared to dentin. The self-adhesive system (RelyX U200) demonstrated superior immediate bond strength compared to ExciTE F DSC, possibly due to the chemical interaction of its functional monomers with Biodentine's components. While Multilink N (self-etch) showed high initial bond strength, its significant decrease over time suggests potential hydrolytic degradation at the interface, a known concern with some self-etch adhesives. According to a study by Odabas *et al.,* in 2013[13] studies on various bonding systems for composite resin restorations to Biodentine at different time points have shown that etch-and-rinse systems exhibited a decrease in shear bond strength, which is consistent with this study. The ExciTE F DSC group, one of the etch-and-rinse systems, demonstrated the lowest shear bond strength compared to other groups in the immediate group. Our findings revealed that the self-adhesive system provided superior bond strength compared to etch-and-rinse adhesives system at all time points, particularly in the immediate bonding group. This is consistent with previous studies[14] although the delayed bonding group exhibited some variability. These findings suggest that the acid-etching process, typically known to induce surface porosity and thereby enhancing micro-retention and bond strength, may not facilitate comparable micro-retention in Biodentine, nor may it substantially improve bond strength between the two materials. Alternatively, it is possible that surface porosity from acid etching did not occur, or that the etching duration was either too brief or too prolonged. These results indicate that while the choice of bonding system can influence initial bond strength, other factors, such as clinical variables and material properties, may also contribute to the long-term performance of composite restorations bonded to Biodentine.

When comparing between different time point, The bar graph (Figure 4) shows that the immediate groups exhibited higher bond strength compared to the delayed groups in all experimental conditions. Our results are at odds with those reported by Odabas *et al.,*[13] which reported an increase in shear bond strength when bonding was delayed for 24 hours. They attributed this to the polymerization shrinkage of composite resins, which can induce tensile stresses on the unset Biodentine, leading to interfacial failure. However, our study used MultiCore Flow, a dual-cure material. Odabas *et al.*[15] used Clearfil Majesty (Kuraray Noritake Dental Inc., Okayama, Japan), a nanohybrid composite. While Clearfil Majesty is a high-quality material, studies have indicated it can generate relatively high polymerization stress. Multi Core Flow, in contrast, has been shown to exhibit a lower degree of conversion compared to some light-cured resins[16] and its polymerization stress has been reported as 10.9 MPa, within the range of many resin composites.[17] This lower polymerization stress likely reduces the tensile forces at the Biodentine-adhesive interface, potentially mitigating the negative impact of immediate bonding observed by Odabas *et al.*[13] Despite this, the long-term decrease in bond strength, especially with Multilink N, suggests that factors beyond initial shrinkage stress, such as hydrolytic degradation, significantly influence bond durability. Another possible explanation for the higher bond strength in the immediate groups compared to the delayed groups is the setting reaction between Biodentine and MultiCore Flow, which may have enhanced the interfacial bond. Further studies are warranted to investigate this hypothesis.

A key limitation of this study was the relatively small sample size (n=10) used for microtensile bond strength testing. This small sample size has several implications. First, it increases the risk of committing Type II errors (false negatives). Second, microtensile bond strength measurements are inherently susceptible to high variability, influenced by factors such as specimen geometry, adhesive application, and inherent material properties. A sample size of ten may be insufficient to adequately represent the full range of this variability, obscuring the true distribution of bond strengths. Furthermore, the limited sample size reduces the external validity of our findings. Finally, with a small sample, the results are more susceptible to being skewed by outlier values. Anomalous bond strengths, arising from premature failures during specimen preparation or inconsistencies during testing, can exert a disproportionately large influence on the overall statistical analysis. Furthermore, while the specific bond strength values obtained in this study may not be directly transferable to other commercially available materials, the relative performance of the tested groups could offer valuable insights for clinicians when selecting materials. While this *in vitro* study provides valuable insights into μTBS of endodontic materials, further research is essential to bridge the gap to clinical outcomes. Studies replicating the oral environment, including thermocycling to simulate temperature fluctuations, could offer a more accurate assessment of long-term bond stability. Additionally, investigating the chemical interactions between endodontic and restorative materials and potential changes within these materials during the setting time could offer a deeper understanding of the bonding mechanisms. Such knowledge could play a critical role in developing improved material formulations and enhancing their clinical performance.

Conclusions

The immediate placement of adhesives on Biodentine demonstrated superior microtensile bond strength than the delayed placement. The self-adhesive system consistently had strong bond strengths at both time intervals. It is suggested that immediate placement and use of self-adhesive system may enhance the bond strength between Biodentine and MultiCore Flow in clinical applications.

Conflicts of Interest

The authors declare no conflict of interest.

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Original Article

Utilization and Satisfaction with Three Languages of Dental Terminology E-book

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Abstract

Objectives: With the rising number of Chinese residents in Thailand and Chinese becoming a global language, compelling messages and communication in healthcare are crucial for accurate information and optimal treatment. This pilot study investigated Thai dentists' utilization and satisfaction with the developed electronic "Three Languages of Dental Terminology (TLDT)" book.

Methods: Three hundred and thirteen dentists who graduated from the College of Dental Medicine, Rangsit University, were invited to the online survey using Google Forms. Demographic data, translation tool usage data, initial TLDT experience, and objectives in using TLDT were explored. TLDT utilization and satisfaction were assessed. Fisher's exact test and Pearson's Chi-Square were utilized to analyze the data.

Results: Eighty-eight (28.1%) dentists responded to the questionnaire. Respondents met foreign patients monthly, with Chinese patients being the most common group. Most dentists lacked Chinese fluency and relied on translation tools (68.2% use Google Translate). Dentists primarily used TLDT to translate Thai to English (53.4%) and English to Thai (42.0%). Thai, English, and Chinese usage patterns aligned with TLDT's goals, indicating successful implementation ($p<0.05$). Regarding utilization, TLDT was significantly associated with all objectives ($p<0.05$) except for spelling accuracy ($p=0.06$). Most respondents reported high satisfaction scores related considerably to finding words, word pairings, and text accuracy ($p<0.05$). Postgraduate levels respectively correlated with increased TLDT content satisfaction ($p=0.02$).

Conclusions: The TLDT e-book demonstrates promise as a valuable resource for health-care personnel, improving dental terminology communication in English and Chinese and might optimize dental care and postgraduate dental education in Thailand.

Keywords: Chinese, dental terminology, electronic book, English, Thai

Introduction

China's economic boom has propelled Mandarin into the world's second-most-spoken language.[1] An incidence of Chinese migrants seeking opportunities occupies Thailand's major cities. Their diverse motivations, from business ventures and education to lifestyle choices, highlight a growing need for effective communication, both verbal and non-verbal, in various sectors, including healthcare services.[2]

In the field of Dentistry, when Thai dentists meet Chinese-speaking patients, language barriers pose significant challenges. Dental clinics frequently visited by Chinese patients often lack the multilingual interpreters that large hospitals commonly provide.[3] The medical and dental history taking, treatment plan explanation, patient safety, and satisfaction are essential components that need to be clearly addressed. Failure to communicate adequately may cause misinterpretation, place patient health at risk, restrict treatment options, and may lead to litigation.[4] Interpreters, while helpful, can be misinterpreted due to the lack of knowledge of dental terminology.[5,6]

Adding another layer of complexity is the vast and specialized vocabulary of dental terminology. Existing resources in Thailand, like the "Thai Dental Terminology" book and an online version of the Thai-English glossary, provide a foundation but lack Chinese translations.[7] Developing the book "Three Languages of Dental Terminology (TLDT)" by our authors was a groundbreaking trilingual electronic book offering Thai, English, and Chinese translations.[8] The Thai terms originate from the book mentioned above. At the same time, the Chinese equivalents come from the "English-Chinese Dictionary of Stomatology," a bilingual dictionary focusing specifically on dental and stomatology terminology.[9] With over 3703 entries covering diverse topics, the electronic TLDT surpasses most bilingual resources and allows convenient searching for dental terminology in any of the three languages. TLDT, in the form of an e-book, comprised the key importance points for digital books in terms of accessibility, convenience, searchability, instant delivery, and cost-effectiveness. This innovative tool bridges the language gap in dentistry, promoting better communication, both speaking and writing, and ultimately, might improve patient outcomes and satisfaction.

However, this e-book hasn't been publicly tested yet. Therefore, this research aimed to explore its utilization and user satisfaction among Thai dentists who graduated from a private dental school, screening the way for further development and optimization of this valuable resource for bridging language barriers in dentistry.

Materials and Methods

The Rangsit University Ethical Committee, by the Declaration of Helsinki, granted this Ethical approval of the cross-sectional pilot study with reference number RSU-ERB 2023-014. Respondents identified as all Thai dentists who graduated from the College of Dental Medicine, Rangsit University, between 2010 and 2021, were invited and recruited to participate in the study. They were contacted through two main channels: direct phone calls and invitations via the "RSU GRADUATE" LINE group announcement. The Dean of the College of Dental Medicine and the LINE Official Account Administrator permitted us to obtain all contact information.

All participating respondents received the exact formal instructions and informed consent to ensure consistency. Questionnaires were employed as the research's primary data collection method and were collected entirely through online links. These links, sent via QR code, included four components: (1) a consent form with a study explanation; (2) a QR code for the Bookcaze application (Figure 1) and TLDT e-book; and (3 and 4) questionnaires presented in both Thai and English versions (Figure 2) which the respondents could either selected according to the language preference. Google Forms facilitated these questionnaires, which ensured respondent anonymity and data confidentiality. The TLDT e-book was hosted on the Bookcaze company website, and participating respondents were granted free access to download the application and use this free e-book. After downloading the application and signing in, the respondents browsed either the TLDT e-book in the “Medical Science” menu bar category or a “Free” store, then a PDF file of the “Thai-English-Chinese dental terminology” e-book could be downloaded and read or search words needed.

Researchers developed the research questionnaire, reviewed by three experts, and underwent content validity.[10] An item objective congruence index of 0.8 demonstrated acceptable content validity.[11] Item response formats included checklists, dichotomous scales, 5-point Likert scales (1 = least, 2 = few, 3 = moderate, 4

= much, 5 = most), and open-ended options for additional comments. The self-administered questionnaire comprised five sections, covering: Part 1: Demographic data (8 items); Part 2: Translation tool usage data (9 items); Part 3: Initial TLDT experience (4 items) and objectives in using TLDT (6 items); Part 4: TLDT utilization assessment (4 aspects); Part 5: TLDT satisfaction assessment (content and usage, four items each).

Six objectives in using TLDT were explored: finding words in other languages, finding synonyms, finding words that often appear together, checking text and spelling accuracy, and accessing other word information.

Questions for TLDT utilization assessment included:

1. To what extent would you use TLDT if you treated Chinese-speaking patients?
2. How necessary is a read-aloud function in TLDT?
3. How necessary are illustrations in TLDT?
4. How necessary are sentence examples in TLDT?

TLDT satisfaction was assessed in two areas: content and usage.

Content satisfaction was evaluated in four aspects:

1. Finding the searched word(s): Did users successfully find the word they were looking for?
2. Accuracy of meaning: Did the dictionary provide the correct definition for the word?
3. Variety of word choices: Were users offered alternative words or synonyms?
4. Trilingual understanding: Could users simultaneously see the word in Thai, English, and Chinese?

Usage satisfaction was investigated in four areas:

1. Search speed: Could users find words quickly and easily?
2. Symbol clarity: Were the app's symbols understandable and intuitive?
3. Font readability: Was the font size and style easy to read on the screen?
4. Word saving: Could users save and retrieve frequently used words?

A sample size calculation (95% confidence interval (CI), 5% margin of error) established a requirement of 271 responses, accounting for an anticipated 40% response rate.(12) Data collection spanned July-October 2023. All data was entered and analyzed using IBM® SPSS® Statistics version 29.0.1.0. Descriptive statistics (frequency, percentage, and median) were employed after the normal distribution was tested, while Fisher's Exact Test and Pearson Chi-Square tests including odd ratio (OR) explored relationships between objectives, utilization, and satisfaction.

Figure 1: QR Code for the Bookcaze application and TLDT e-book.

Figure 2: QR Code for the questionnaires presented in both Thai and English versions.

Results

Three hundred and thirteen RSU graduates were invited to participate in the study, and 88 responded (28.1% response rate). All respondents were Thai, with a slight female majority (54 females, 61.4% vs. 34 males, 38.6%). The respondents' ages ranged from 25 to 40 years, averaging 29. Most (84.1%) used Thai and English, while 9.1% used Thai for patient communication. Only five respondents (5.7%) were fluent in all three languages (Thai, Chinese, and English), while one respondent (1.1%) was able to speak Thai, English, and Korean. Two-thirds (68.2%) were pursuing dental specializations in various fields, 17.0% were already specialists, and 14.8% were general dentists.

Regarding respondents' work locations, 67.0% worked in the capital city, Bangkok, 12.5% in surrounding areas (Pathum Thani, Samut Prakan, Nakhon Pathom, Nonthaburi), and 20.5% in other provinces. Most of these (71.6%) worked in one setting (either private clinic, hospital, or university), 25.0% in two, and 3.4% in three settings. Eighty-five (96.6%) respondents encountered foreign patients monthly, with only three (3.4%) seeing no foreign patients. Fifty-two respondents (59.1%) met 1-5 foreign patients, eighteen (20.5%) met 6-10, and fifteen (16.9%) met more than 10. Regarding patients' race, 58.0% met Chinese patients, while 42.0% did not. Of those who saw Chinese patients, 82.4% treated 1-5, 15.7% treated 6-10, and only 1.9% treated more than 10 Chinese patients monthly.

Nevertheless, most respondents (93.2%) could not speak Chinese, while only 6 (6.8%) could. Google Translate was the most popular tool for communication, and it was used by two-thirds of respondents (68.2%). The remaining apps used were ChatGPT, MediBabble, and an online dictionary. Three respondents (two in the hospitals and one in a clinic) relied on interpreters. Learning, education, academic writing, vocabulary searches, and novel reading were performed apart from communication from the mentioned apps. English was the primary language used, with translation needed only for occasional interactions with Chinese patients. Twenty-eight respondents (70.0%) were truly satisfied with the mentioned apps, 10 (25.0%) were moderately satisfied, and 2 (5.0%) were somewhat satisfied. Most respondents (83, or 94.3%) preferred smartphones for these translation apps, while the remaining 5 (5.7%) used tablets and computers.

After using the TLDT e-book, most respondents (47, or 53.4%) used it for Thai-to-English translation, followed by English-to-Thai by 37 (42.0%). Furthermore, the median assessment scores of utilization for TLDT were high (Likert scale 4) across all four questions. Overall, the median satisfaction score with the content and usage of TLDT was also high (Likert scale 4). Therefore, we stratified the data according to the median score into two groups (least to moderate versus much to most) for further analysis.

Table 1 shows the statistically significant pattern of TLDT usage related to six objectives in using TLDT, obtained for Thai-to-English (according to the objectives shown consecutively in Table 1, OR=8.5; 95% CI 3.1, 22.8 $p<0.001$; OR=10.8; 95% CI 4.0, 29.4 $p<0.001$; OR=8.8; 95% CI 3.3, 23.6 $p<0.001$; OR=10.2; 95% CI 3.8, 27.5 $p<0.001$; OR=9.1; 95% CI 3.4, 24.2 $p<0.001$; OR=5.7; 95% CI 2.2, 14.7 $p<0.001$, respectively), and English-to-Thai (OR=4.8; 95% CI 1.8, 13.0 $p<0.001$; OR=8.2; 95% CI 3.1, 21.7 $p<0.001$; OR=4.0; 95% CI 1.7, 9.9 $p<0.001$; OR=4.1; 95% CI 1.6, 10.4 $p<0.001$; OR=3.8; 95% CI 1.5, 9.6 $p=0.01$; OR=3.2; 95% CI 1.3, 7.8 $p=0.01$, respectively). A similar pattern was also demonstrated with Thai-to-English-to-Chinese translation across all objectives ($p<0.05$).

Considering the relationship of interested research data, Table 2 shows the respondents' demographic data with TLDT utilization or satisfaction. Age, gender, workplace province, and workplace type had no statistically significant relationship with TLDT utilization or satisfaction. The only exception was the educational level, postgraduate, related to content satisfaction with the TLDT (OR=6.2; 95% CI 1.4, 27.5; $p=0.02$).

Table 3 shows that TLDT utilization was statistically significant with all six objectives in using the TLDT except spelling accuracy (according to the objectives shown consecutively in Table 3, OR=3.7; 95% CI 1.3, 10.6 $p=0.02$; OR=4.6; 95% CI 1.4, 15.3 $p=0.01$; OR=4.1; 95% CI 1.2, 13.6 $p=0.02$; OR=5.3; 95% CI 1.7, 16.3 $p<0.001$; OR=5.5; 95% CI 1.5, 20.6 $p<0.001$, respectively). Interestingly, the content satisfaction levels were significantly related to three objectives: finding words in other languages (OR=6.7; 95% CI 1.3, 34.7; $p=0.03$), finding words that often appear together (OR=7.8; 95% CI 1.1, 36.3; $p=0.04$), and checking text accuracy (OR=5.4; 95% CI 1.1, 27.8; $p=0.04$). A similar pattern was also revealed for usage satisfaction (OR=3.2; 95% CI 1.1, 9.4; $p=0.03$; OR=9.5; 95% CI 2.0, 44.5; $p<0.001$; and OR=3.4; 95% CI 1.1, 10.1; $p=0.03$, respectively).

Regarding unfound words in TLDT, 13 respondents (14.8%) reported encountering some (29 unfound words). Eight words were present in TLDT but were not found with the respondents' search terms. The remaining 21 unfound words were absent as well.

Discussion

This pilot cross-sectional study used an online questionnaire to investigate 88 Thai dentists' utilization and satisfaction with a Thai-English-Chinese dental terminology e-book. The results showed that the developed TLDT e-book is valuable for dentists and postgraduate dental students in Thailand. The e-book is easy to use and con-

Table 1: Relationship between the pattern of TLDT usage and objectives in using the TLDT.

		Find words in other languages		p*	Synonym/Similar words		p*	Words that often appear together		p*	Accuracy of text		p*	Accuracy of spelling		p*	Other information about the word		p*
		Least to moderate (n=34)	Much to most (n=54)		Least to moderate (n=46)	Much to most (n=42)		Least to moderate (n=48)	Much to most (n=40)		Least to moderate (n=38)	Much to most (n=50)		Least to moderate (n=37)	Much to most (n=51)		Least to moderate (n=50)	Much to most (n=38)	
Translate Thai to English	Least to moderate	26 (76.5%)	15 (27.8%)	0.00	33 (71.7%)	8 (19.0%)	0.00	33 (68.8%)	8 (20.0%)	0.00	29 (76.3%)	12 (24.0%)	0.00	28 (75.7%)	13 (25.5%)	0.00	32 (64.0%)	9 (23.7%)	0.00
	Much to most	8 (23.5%)	39 (72.2%)		13 (28.3%)	34 (81.0%)		15 (31.2%)	32 (80.0%)		9 (23.7%)	38 (76.0%)		9 (24.3%)	38 (74.5%)		18 (36.0%)	29 (76.3%)	
Translate Thai to Chinese	Least to moderate	28 (82.4%)	33 (61.1%)	0.06	34 (73.9%)	27 (64.3%)	0.36	36 (75.0%)	25 (62.5%)	0.25	29 (76.3%)	32 (64.0%)	0.25	27 (73.0%)	34 (66.7%)	0.64	40 (80.0%)	21 (55.3%)	0.02
	Much to most	6 (17.6%)	21 (38.9%)		12 (26.1%)	15 (35.7%)		12 (25.0%)	15 (37.5%)		9 (23.7%)	18 (36.0%)		10 (27.0%)	17 (33.3%)		10 (20.0%)	17 (44.7%)	
Translate Chinese to English	Least to moderate	31 (91.2%)	44 (81.5%)	0.36	42 (91.3%)	33 (78.6%)	0.13	43 (89.6%)	32 (80.0%)	0.24	35 (92.1%)	40 (80.0%)	0.14	34 (91.9%)	41 (80.4%)	0.22	46 (92.0%)	29 (76.3%)	0.07
	Much to most	3 (8.8%)	10 (18.5%)		4 (8.7%)	9 (21.4%)		5 (10.4%)	8 (20.0%)		3 (7.9%)	10 (20.0%)		3 (8.1%)	10 (19.6%)		4 (8.0%)	9 (23.7%)	
Translate Chinese to Thai	Least to moderate	29 (85.3%)	38 (70.4%)	0.13	37 (80.4%)	30 (71.4%)	0.45	39 (81.2%)	28 (70.0%)	0.32	31 (81.6%)	36 (72.0%)	0.33	29 (78.4%)	38 (74.5%)	0.80	44 (88.0%)	23 (60.5%)	0.01
	Much to most	5 (14.7%)	16 (29.6%)		9 (19.6%)	12 (28.6%)		9 (18.8%)	12 (30.0%)		7 (18.4%)	14 (28.0%)		8 (21.6)	13 (25.5%)		6 (12.0%)	15 (39.5%)	
Translate English to Thai	Least to moderate	27 (79.4%)	24 (44.4%)	0.00	37 (80.4%)	14 (33.3%)	0.00	35 (72.9%)	16 (40.0%)	0.00	29 (76.3%)	22 (44.0%)	0.00	28 (75.7%)	23 (45.1%)	0.01	35 (70.0%)	16 (42.1%)	0.01
	Much to most	7 (20.6%)	30 (55.6%)		9 (19.6%)	28 (66.7%)		13 (27.1%)	24 (60.0%)		9 (23.7%)	28 (56.0%)		9 (24.3%)	28 (54.9%)		15 (30.0%)	22 (57.9%)	
Translate English to Chinese	Least to moderate	27 (79.4%)	41 (75.9%)	0.80	35 (76.1%)	33 (78.6%)	0.81	36 (75.0%)	32 (80.0%)	0.62	31 (81.6%)	37 (74.0%)	0.45	30 (81.1%)	38 (74.5%)	0.61	39 (78.0%)	29 (76.3%)	1.00
	Much to most	7 (20.6%)	13 (24.1%)		11 (23.9%)	9 (21.4%)		12 (25.0%)	8 (20.0%)		7 (18.4%)	13 (26.0%)		7 (18.9%)	13 (25.5%)		11 (22.0%)	9 (23.7%)	
Translate Thai to English to Chinese	Least to moderate	34 (100.0%)	41 (75.9%)	0.00	45 (97.8%)	30 (71.4%)	0.00	45 (93.8%)	30 (75.0%)	0.02	37 (97.4%)	38 (76.0%)	0.01	36 (97.3%)	39 (76.5%)	0.01	48 (96.0%)	27 (71.1%)	0.00
	Much to most	0 (0.0%)	13 (24.1%)		1 (2.2%)	12 (28.6%)		3 (6.2%)	10 (25.0%)		1 (2.6%)	12 (24.0%)		1 (2.7%)	12 (23.5%)		2 (4.0%)	11 (28.9%)	

*Fisher's Exact Test/Pearson Chi-Square tests

Table 2: Relationship between demographic data of the respondents and utilization and satisfaction of TLDT

Variables	Utilization (N=88)			*p**	Satisfaction of content (N=88)			*p**	Satisfaction of usage (N=88)			*p**
	Least (n=3)	Moderate (n=16)	Most (n=69)		Least (n=0)	Moderate (n=9)	Most (n=79)		Least (n=3)	Moderate (n=16)	Most (n=70)	
Age (years)												
< 29	1 (33.3%)	7 (43.8%)	31 (44.9%)	0.92	0 (0%)	3 (33.3%)	36 (45.6%)	0.48	1 (50.0%)	6 (37.5%)	32 (45.7%)	0.83
≥ 29	2(66.7%)	9 (56.2%)	38 (55.1%)		0 (0%)	6 (66.7%)	43 (54.4%)		1 (50.0%)	10 (62.5%)	38 (54.3%)	
Sex												
Male	3 (100.0%)	5 (31.2%)	26 (37.7%)	0.08	0 (0.0%)	3 (33.3%)	31 (39.2%)	1.00	1 (50.0%)	3 (18.7%)	30 (42.9%)	0.19
Female	0 (0.0%)	11 (68.8%)	43 (62.3%)		0 (0.0%)	6 (66.7%)	48 (60.8%)		1 (50.0%)	13 (81.3%)	40 (57.1%)	
Education												
General dentist	2 (66.7%)	1 (6.2%)	10 (14.5%)		0 (0.0%)	4 (44.4%)	9 (11.4%)	0.02	0 (0.0%)	3 (18.7%)	10 (14.3%)	0.27
Further study	1 (33.3%)	11 (68.8%)	48 (69.6%)	0.09	0 (0.0%)	5 (55.6%)	55 (69.6%)		2 (100.0%)	13 (81.3%)	45 (64.3%)	
Specialist	0 (0.0%)	4 (25.0%)	11 (15.9%)		0 (0.0%)	0 (0.0%)	15 (19.0%)		0 (0.0%)	0 (0.0%)	15 (21.4%)	
Province of workplaces												
Bangkok	2 (66.7%)	9 (56.2%)	48 (69.6%)		0 (0.0%)	5 (55.6%)	54 (68.4%)		1 (50.0%)	8 (50.0%)	50 (71.4%)	
Perimeter	0 (0.0%)	2 (12.5%)	9 (13.0%)	0.70	0 (0.0%)	2 (22.2%)	9 (11.4%)	0.62	0 (0.0%)	2 (12.5%)	9 (12.9%)	0.27
Other provinces	1 (33.3%)	5 (31.3%)	12 (17.4%)		0 (0.0%)	2 (22.2%)	16 (20.2%)		1 (50.0%)	6 (37.5%)	11 (15.7%)	
Workplaces												
Private Clnic	1 (33.3%)	9 (56.2%)	48 (69.6%)		0 (0.0%)	4 (44.4%)	54 (68.3%)	0.08	1 (50.0%)	9 (56.3%)	48 (68.6%)	0.73
Hospital	1 (33.3%)	4 (25.0%)	15 (21.7%)	0.47	0 (0.0%)	2 (22.2%)	18 (22.8%)		1 (50.0%)	5 (31.2%)	14 (20.0%)	
Private Clinic and University	1 (33.3%)	3 (18.8%)	6 (8.7%)		0 (0.0%)	3 (33.3%)	7 (8.9%)		0 (0.0%)	2 (12.5%)	8 (11.4%)	

*Fisher's Exact Test/Pearson Chi-Square tests

Table 3: Relationship between objectives in using TLDT and utilization and satisfaction with TLDT

The objective for using TLDT		Utilization (N=88)		p*	Satisfaction of content (N=88)		p*	Satisfaction of usage (N=88)		p*
		Least to moderate (n=19)	Much to most (n=69)		Least to moderate (n=9)	Much to most (n=79)		Least to moderate (n=18)	Much to most (n=70)	
Find words in other languages	Least to moderate	12 (63.2%)	22 (31.9%)	0.02	7 (77.8%)	27 (34.2%)	0.03	11 (61.1%)	23 (32.9%)	0.03
	Much to most	7 (36.8%)	47 (68.1%)		2 (22.2%)	52 (65.8%)		7 (38.9%)	47 (67.1%)	
Synonym/Similar words	Least to moderate	15 (78.9%)	31 (44.9%)	0.01	7 (77.8%)	39 (49.4%)	0.16	13 (72.2%)	33 (47.1%)	0.68
	Much to most	4 (21.1%)	38 (55.1%)		2 (22.2%)	40 (50.6%)		5 (27.8%)	37 (52.9%)	
Words that often appear together	Least to moderate	15 (78.9%)	33 (47.8%)	0.02	8 (88.9%)	40 (50.6%)	0.04	16 (88.9%)	32 (45.7%)	0.00
	Much to most	4 (21.1%)	36 (52.2%)		1 (11.1%)	39 (49.4%)		2 (11.1%)	38 (54.3%)	
Accuracy of text	Least to moderate	14 (73.7%)	24 (34.8%)	0.00	7 (77.8%)	31 (39.2%)	0.04	12 (66.7%)	26 (37.1%)	0.03
	Much to most	5 (26.3%)	45 (65.2%)		2 (22.2%)	48 (60.8%)		6 (33.3%)	44 (62.9%)	
Accuracy of spelling	Least to moderate	12 (63.2%)	25 (36.2%)	0.06	6 (66.7%)	31 (39.2%)	0.16	10 (55.6%)	27 (38.6%)	0.28
	Much to most	7 (36.8%)	44 (63.8%)		3 (33.3%)	48 (60.8%)		8 (44.4%)	43 (61.4%)	
Other information about the word	Least to moderate	16 (84.2%)	34 (49.3%)	0.00	8 (88.9%)	42 (53.2%)	0.07	14 (77.8%)	36 (51.4%)	0.06
	Much to most	3 (15.8%)	35 (50.7%)		1 (11.1%)	37 (46.8%)		4 (22.2%)	34 (48.6%)	

*Fisher's Exact Test/Pearson Chi-Square tests

tains a comprehensive list of Thai, English, and Chinese dental terminologies. Dentists and postgraduate dental students are satisfied with the TLDT e-book and believe it helps improve communication with foreign patients or writing for academic purposes.

Because of different types of communication, such as written, verbal, or non-verbal communication(13), using TLDT via verbal communication was not prominent in this study. Although most respondents encountered foreign patients monthly, with Chinese patients being the most common, most dentists cannot speak Chinese. English was the primary language used for occasional interactions with Chinese patients. Google Translate is the most popular translation tool, similar to the previous studies.(14,15) Even though the number of dentists using Chinese translation was relatively small, from our results, the pattern of dentist usage from Thai to English, English to Thai, and Thai to English to Chinese revealed a significant relationship to the six objectives of TLDT. This study, therefore, highlights the need for trilingual translation tools for dental terminology.(16,17)

Notably, an interesting finding emerged. Dentists pursuing specialization showed a statistically significant link with higher content satisfaction. Those used them for communication, learning, and academic writing, similar to the published data.(18) Dentists in postgraduate programs are likelier to write educational documents, leading to greater TLDT utilization and satisfaction. This result aligns with previous researches suggesting specialists seek educational resources like e-books for their specialized terminology and complex information needs.(19-21)

Usage patterns involving Thai-English, English-Thai, and Thai-English-Chinese translations were significantly associated with all six TLDT objectives. This result suggests that common usage aligns closely with the e-book's intended purpose. This pattern strongly correlated with key objectives like finding words in other languages, identifying synonyms, and checking text accuracy. Therefore, the e-book primarily serves as a cross-language dental terminology lookup tool between Thai and English.

This study also explored the relationship between TLDT objectives, utilization, and user satisfaction. While utilization was significantly linked to five out of six objectives (excluding spelling accuracy), user satisfaction only correlated with finding words in other languages, identifying words that often appear together, and text accuracy. This suggests that the equivalent finding of the core aim of cross-language terminology lookup and proper word usage primarily drive satisfaction.(18) Additionally, the closer match between utilization and objectives than satisfaction and objectives suggests that respondents used the TLDT effectively for its intended purpose.

Limitations of this preliminary study include a relatively small sample size and a low response rate (28.12%) compared to the expected 40%.(12) This could be due to recent concerns about phone scams in Thailand(22) and difficulty reaching respondents with outdated contact information. Future research could include interpreters or wider dental professional clinicians and utilize diverse contact methods to improve participation and generalizability of the study. Administrations of the questionnaire to calculate test-retest reliability should be performed to strengthen the findings. A few respondents reported encountering unfound words in the TLDT e-book, suggesting potential areas for improvement. The TLDT itself includes incomplete three-language coverage, leading to missing search terms. Additionally, respondents suggested improvements like adding pronunciation, pictures, vocabulary usage examples, translation explanations, and categorizing word lists based on dental departments or difficulty. Further development and public testing are needed to refine and optimize these tools for maximum impact.

Conclusions

This study suggests that multilingual e-books like TLDT can significantly improve the accessibility of dental terminology in Thai, English, and Chinese. The TLDT e-book is a helpful tool for enhancing communication of dental terminologies between Thai, English, and Chinese in Thailand. The e-book is easy to use and contains a comprehensive list of Thai, English, and Chinese dental terminologies. Dentists and dental students who participated in the study reported that they are satisfied with the TLDT e-book and believe it helps improve communication with foreign patients and the writing of academic papers.

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Conflicts of Interest

The authors declare no conflict of interest.

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The Effect of Different Surface Treatments of Shear Bond Strength of Repaired Polymer-infiltrated Ceramic Network Materials

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Abstract

Objectives: This study aimed to determine the alternative surface treatment method for repairing aged polymer-infiltrated ceramic network materials (PICNs) utilizing a shear bond strength (SBS) test.

Methods: A PICNs block (VITA Enamic®) was cut into 5x5x5 mm^3 followed by thermocycling for 10,000 cycles. The specimens were then randomly divided into four groups (n=12), based on different surface treatments. Group HF+Si: treated with a 9.5% hydrofluoric acid and silane application, Group HF+Si+He: treated with a 9.5% hydrofluoric acid and silane application followed by an application of a hydrophobic resin monomer, Group MEP: treated with a self-etching ceramic primer, Group MEP+He: treated with a self-etching ceramic primer followed by an application of a hydrophobic resin monomer. All specimens were repaired with a resin composite and underwent a thermocycling aging process for 10,000 cycles before measuring shear bond strength.

Results: One-way ANOVA revealed a significant difference in SBS among all groups. Group MEP exhibited a significantly lowest mean SBS value ($p<0.05$), while, mean SBS values from groups HF+Si, HF+Si+He, and MEP+He did not show statistically significant differences.

Conclusions: Treating aged PICNs with only self-etching ceramic primer group provided an insufficient shear bond strength. However, when a hydrophobic resin monomer was applied after conditioning with self-etching ceramic primer, shear bond strength was distinctly improved to a comparable level to those treated with 9.5% hydrofluoric acid and silane primer.

Keywords: hydrofluoric acid, hyphobic resin monomer, self-etching ceramic primer, silane, PICNs

Introduction

Advanced developments in digital technology and manufacturing processes have resulted in a dramatic paradigm shift in dentistry and the widespread use of computer-aided design/computer-aided manufacturing (CAD/CAM) in the fabrication of indirect dental restorations.(1,2) While various dental ceramics are currently improved and available for CAD/CAM fabrication(2,3), they are still brittle and susceptible to cracks and fractures. Such fractures are difficult to repair(4-6), impairing restoration longevity. As a result, the trend of development aims to reduce risk of fracture in indirect posterior restorations.(5)

Since 2013, the only one commercially available polymer-infiltrated ceramic materials (PICNs) with CAD/CAM technology, VITA Enamic® (VITA Zahnfabrik, Bad Säckingen, Germany), has been introduced to dental profession. VITA Enamic® is composed of a network of feldspathic ceramics infiltrated by a polymeric phase.(4,7-9) The polymer-infiltrated ceramic materials exhibited lower brittleness, rigidity, and hardness than glass ceramics. They also demonstrated increased flexibility and fracture toughness.(7,9) This may result in an improvement in stress distribution, particularly during the mastication process.(10) Nevertheless, several factors, including high masticatory forces, parafunctional habits, and internal defects within the material, critically impact the success of dental restorations in a long period of clinical service. Crack propagation induced by these factors may lead to fracture of restoration, significantly compromising longevity.(7-9) According to a three-year clinical research study conducted by Spitznagel *et al.*,(11) they discovered that fractures were the primary cause of failures in 103 PICNs CAD/CAM restorations which were unacceptable bulk fractures and chipping. The repairable failed restorations were repaired with resin composite and showed no failure up to three-year follow up.(11) Among those chipping, non-catastrophic fractures were repairable, extending esthetics and functional preservation of restorations.(12,13)

Previous studies have been reported that the most effective technique for repairing polymer-infiltrated ceramic materials was etching with hydrofluoric acid followed by silane application(14, 15) and re-restoring with resin composite.(13) However, hydrofluoric acid was considered a hazardous substance, especially when it was spilled on tissues. The aggressiveness of this acid can cause burns that frequently result in deep tissue necrosis.(13,16) The alternative less aggressive acid has been developed in order to reduce such complication during repairing procedure. A new self-etching glass-ceramic primer (Monobond Etch & Prime; Ivoclar Vivadent, Schaan, Liechtenstein) consists of four distinct compositions including an ammonium polyfluoride, phosphoric acid ester, solvent and silane enclosing in one bottle.(17) Murillo *et al.,*(18) compared the effects of the new self-etching primer with the contemporary technique on bonding to glass-ceramic and resin cement. The result indicated no statistically significant difference in microtensile bond strength between the two groups. However, no study has examined the effectiveness of either self-etching primer alone or combined with a hydrophobic resin on the repair of polymer-infiltrated ceramic network materials.

The application of bonding agents on old ceramic before repairing with resin composite has also been discussed.(19,20) According to certain studies, using bonding agents, ones containing hydrophobic resin monomer, improved the bond between glass ceramics and resin composites.(19,20) On the other hand, the systematic review and meta-analysis performed by Nogueira *et al.,*(21) showed insufficient evidence to encourage using an adhesive system as an adjunctive surface treatment before repairing. With this inconsistency, the study about the benefit of a hydrophobic resin application on repairing polymer-infiltrated ceramic network materials surface, especially when combined with self-etch ceramic primer is scarce.

Altogether, these raised the question whether the new self-etching ceramic primer combined with a hydrophobic resin monomer could effectively repair the polymer-infiltrated ceramic network materials (PICNs). Therefore, the purpose of this study was to determine the different surface treatment methods for repairing polymer-infiltrated ceramic network material (PICNs) using shear bond strength. Additionally, an application of a hydrophobic resin monomer before placement of resin composites was also investigated in the present study.

Materials and Methods

Specimen preparation

A total of 6 CAD-CAM PICNs block (VITA Enamic®, VITA Zahnfabrik, Bad Säckingen, Germany), size 12×14×18 mm^3, were cut into 5x5x5 mm^3 slices using a low-speed diamond cutting (Isomet Low Speed Saw, Buehler, USA) under constantly running water followed by a thermocycling aging process was simulated using dwelling in water between temperatures of 5-55ºC for 10,000 cycles with a 60 s dwell time per bath (THE1400, SD Mechatronik GmbH). All specimens were then embedded in a self-curing acrylic resin. Each block was polished with five-step silicon carbide abrasive papers (200, 400, 600, 800, and 1,000 grit) using a polishing machine (NANO 2000, Pace Technologies, USA) to achieve standardized smooth surfaces before being cleaned with water for 5 minutes in an ultrasonic cleaner (Bransonic, Germany). All processes of specimen preparation are shown in Figure 1.

Surface treatment

The details of the material used in the study are shown in Table 1, and the experimental procedures are displayed in Figure 1. The specimens were randomly divided into four groups according to the surface treatment (n=12).

Group1 (HF+Si): etch with 20-µl of 9.5% hydrofluoric acid (PORCELAIN ETCHANT, Bisco, Schaumburg, USA) for 60 seconds, wash with air-water spray for 60 seconds, and air-dry for 10 seconds. Afterward, apply a 10-µl Silane Primer (Kerr, Brea, USA) in one direction with a 1.5-mm microbrush (Cotisen®, Huanghua promise dental, Hebei, China), wait 60 seconds, and drying with warm air from a 10-cm distance for 20 seconds. The warm air was calibrated to 60°C using a thermometer (Testo Saveris 2-T3, Testo SE & Co., Germany).

Group 2 (HF+Si+He): same as group 1, additionally, apply a 10-µl Heliobond (Ivoclar Vivadent, Schaan, Liechtenstein) in one direction with a 1.5-mm microbrush (Cotisen®, Huanghua promise dental, Hebei, China) and photopolymerized (Demi™Plus, Kerr, Orange, CA, USA) for 20 seconds

Group 3 (MEP): applying 20-µl Monobond Etch & Prime (Ivoclar Vivadent, Schaan, Liechtenstein) using a 1.5-mm microbrush (Cotisen®, Huanghua promise dental, Hebei, China), agitate on the surface for 20 seconds, and wait for 40 seconds. Then, thoroughly rinse off with water for 20 seconds and drying the specimen with warm air with the same calibration as used in group 1.

Group 4 (MEP+He): same as group 3, additionally, apply a 10-µl Heliobond (Ivoclar Vivadent, Schaan, Liechtenstein) in one direction with a 1.5-mm microbrush (Cotisen®, Huanghua promise dental, Hebei, China) and photopolymerized (Demi™Plus, Kerr, Orange, CA, USA) for 20 seconds

Repair method

A clear silicone mold with 3x3 mm^2 (wide x height) was placed at the center of each specimen to standardize the bonding area. Resin composite (Filtek™ Z350 XT, 3M ESPE, St. Paul, USA) with thickness of 1.5 mm. was applied in the mold and photopolymerized. The another increment with same thickness was then applied to provide 3 mm thickness of resin composite restoration. A light-polymerizing unit (Demi™Plus, Kerr, Orange, CA, USA), with a diameter size of 8 mm, was used to photopolymerize each increment for 40 seconds, the tip of the unit was touched to the mold at an intensity of 1,100 mW/cm^2, the device was calibrated with a radiometer (Optilux Radiometer, Kerr, Orange, CA, USA). After the polymerization, the silicone mold was carefully detached using a scalpel, and excess resin composite material was also gently removed. The specimens were then kept in

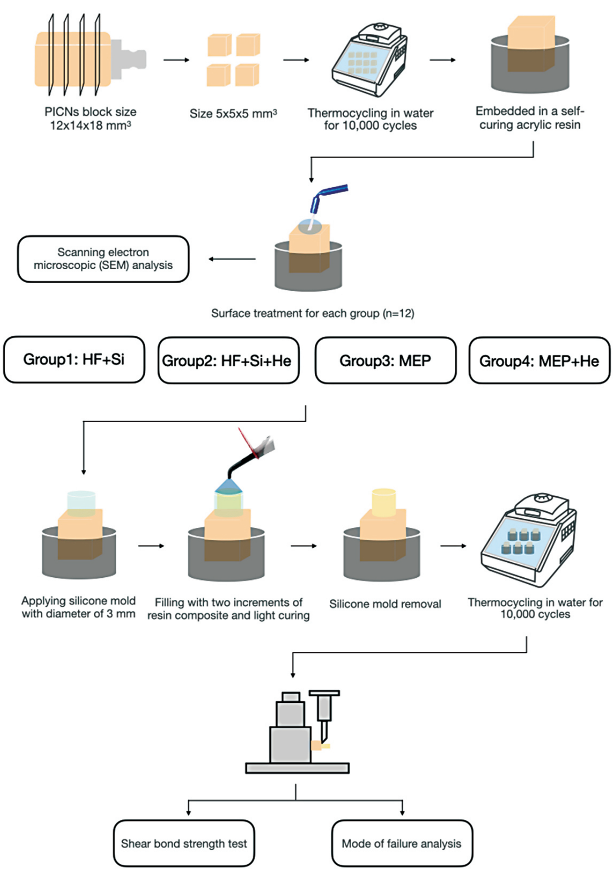

Figure 1: Flow chart of the experimental procedures.

Table 1: Material compositions.

Material	Type	Composition	Lot No.
VITA Enamic® (VITA Zahnfabrik, Bad Säckingen, Germany)	Polymer-infiltrated ceramic network materials (PICNs)	Ceramic content (86% wt, 75% vol): SiO_2 (58-63%), Al_2O_3 (20-23%), Na_2O (9-11%), K_2O (4-6%), B_2O_3 (0.5-2%), ZrO_2<1%, CaO<1% Polymer content (14% wt, 25% vol): UDMA, TEGDMA	99280
Filtek™ Z350 XT (3M ESPE, St. Paul, USA)	Nanofill resin composite	Filler: silica filler, non-agglomerated/non-aggregated 4 to 11 nm zirconia filler, and aggregated zirconia/silica cluster filler. Resin: Bis-GMA, UDMA, TEGDMA, Bis-EMA, PEGDMA	9783163
PORCELAIN ETCHANT (Bisco, Schaumburg, USA)	Hydrofluoric acid	9.5% Buffered hydrofluoric acid gel	2300001967
Monobond Etch & Prime (Ivoclar Vivadent, Schaan, Liechtenstein)	Self-etching ceramic primer	Butanol, tetrabutylammonium dihydrogen trifluoride, methacrylate phosphoric acid ester, bis(triethoxysilyl) ethane, silane methacrylate, colourant, ethanol, water	Z03CD9
Silane Primer (Kerr, Brea, USA)	Silane coupling agent	Ethanol, (1-methylethylidene)bis[4,1-phenyleneoxy(2- hydroxy-3,1-propanediyl)] bismethacrylate, Poly(oxy-1,2-ethanediyl), α,α'-[(1- methylethylidene)di-4,1-phenylene] bis[ω-[(2- methyl-1-oxo-2-propen-1-yl)oxy]-, 2,2'-ethylenedioxydiethyl dimethacrylate 3-trimethoxysilylpropyl methacrylate	9730905
Heliobond (Ivoclar Vivadent, Schaan, Liechtenstein)	Light-curing, single-component hydrophobic resin monomer	Bis-GMA, TEGDMA, photoinitiator	Z02TZ2

distilled water at 37°C for 24 hours before thermocycling in water between 5 and 55°C for 10,000 cycles with a 60-s dwell time per bath (THE1400, SD Mechatronik GmbH).

Shear bond strength test

After thermocycling, shear bond strength test was conducted using a universal testing machine (EZ-S500N, SHIMADZU, JAPAN). Each specimen was attached to a metal mold. And was loaded with a crosshead speed of 1 mm per minute and applied at the bonding interface until failure. The bond strength was recorded and calculated by Trapezium 2 program. The mean and standard deviation of shear bond strength in each group were analyzed.

Mode of failure analysis

Fractured specimens were examined under a stereomicroscope (SZ 61, OLYMPUS, JAPAN) to evaluate the failure mode at a magnification of 15X. Modes of failure were classified into 4 types as following: adhesive, cohesive in either the PICNs or resin composite, and mixed failure. The percentage of each mode was calculated based on the total specimens of each group.

Scanning electron microscopic (SEM) analysis

The two representative specimens were subjected to SEM analysis to evaluate topographic change after surface treatment by rinsing with deionized water, drying with oil-free air, sputter coating with a conductive 6-nm gold layer, and analyzing the surface structure with an SEM (JSM-6610LV Scanning Electron Microscope JEOL, USA) at an acceleration voltage 20 kV. Moreover, the two specimens of each group were selected after the shear bond strength test to display the failure surface.

Statistical analysis

Statistical analysis was performed using SPSS software (IBM SPSS statistics version 29.0.1.0, IBM; Armonk, NY, USA). All data was analyzed with a Shapiro-Wilk to test the normality of data distribution. The One-way ANOVA was used to compare the effect of surface treatment between groups in which the level of confident at 95% was considered to be statistically significant.

Result

Shear bond strength (SBS) and failure mode analysis

SBS values were normally distributed. Mean SBS values and standard deviations each group are shown in Table 2. One-way ANOVA demonstrated a statistically significant difference ($p<0.05$) of mean SBS values among all groups. Group 3 showed the lowest mean SBS values comparing to others. However, groups 1, 2, and 4 did no statistical difference.

The percentage of mode of failure is presented in Figure 2. Adhesive failure was the predominant mode observed exclusively in Group 3. In contrast, Groups 1, 2, and 4 primarily exhibited a mixed mode, although adhesive failure was also presented.

Scanning electron microscopic (SEM) analysis

Representative images of surface topography after each experimental protocol using SEM analysis are displayed in Figures 3. Abundant microporosity between the intact interpolymer network was observed in Group 1 (Figure 3B). Whereas slight surface roughness was observed in Group 3 (Figure 3D) which was similar to thermocyled PICNs surface (Figure 3A). However, a flat and smooth surface was found in either Group 2 (Figure 3C) or Group 4 (Figure 3E). Additionally, surface morphology of representative fracture surfaces was investigated and are presented in Figures 4. Fracture surface at adhesive interface was seen in adhesive failure mode (Figure 4A). For mixed mode of failure, partial fracture of either PICNs or resin composite could be seen as shown in Figure 4B and Figure 4C respectively.

Discussion

During the repair process, surface conditioning of the repaired substrate is the most critical factor determining success. Moreover, different surface conditioning methods can induce distinct topographic changes in various ceramic materials, leading to variations in bond strength.(22) The present study investigated different surface treatment protocols for repairing aged PICNs using shear bond strength test. The result showed that aged PICNs with different surface treatments exhibited different bond performances. The primary finding of the study was that the repairing PICNs with a self-etching ceramic primer alone was insufficient compared to conventional techniques, whereas the additional step of application of hydrophobic resin provided the effective surface treatment before repairing aged PICNs.

In line with the present study, previous research demonstrated that hydrofluoric acid treatment followed by the application of a silane coupling agent was the most effective method for surface treatment of the PICNs, including aged PICNs.(14,15) Eighty percent of PICNs consists of a feldspathic network, which is acid-labile. Hydrofluoric acid partially dissolves the glass-ceramic network, creating a distinct “honeycomb” pattern on material surface, as observed in the SEM image (Figure 3B).(12,23,24) When pre-hydrolyzed silane is applied, its inorganic component reacts with silicon dioxide on the etched glass surface forming siloxane bonds, while the methoxy groups bond with methacrylate-based resins. This silane-treated porosity allows micromechanical interlocking when resin cement is polymerized, resulting in a strong bond (Group HF+Si).(25-27)

Meanwhile, twenty percent of PICNs consists of a patented high-temperature and high-pressure polymerized resin, which resulted in a high degree of conversion of polymer-infiltration.(28) This property may reduce the potential for chemical copolymerization between free

Table 2: Means ± SD of the shear bond strength values (MPa) in each group.

Surface treatment (n=12)	Group 1 (HF+Si)	Group 2 (HF+Si+He)	Group 3 (MEP)	Group 4 (MEP+He)
Shear bond strength (MPa)	21.44±3.58^{A}	21.48±1.64^{A}	10.28±1.87^{B}	19.60±2.12^{A}

Means ± SD in MPa. Different capital letters in each row mean significantly different at $p<0.05$.
HF: Hydrofluoric acid; Si: Silane primer; He: Heliobond; MEP: Monobond Etch & Prime

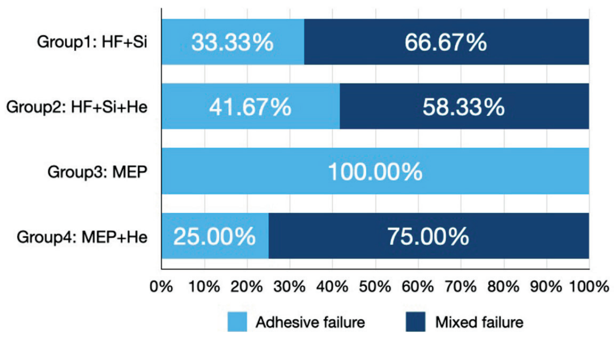

Figure 2: Mode of failure in each group.

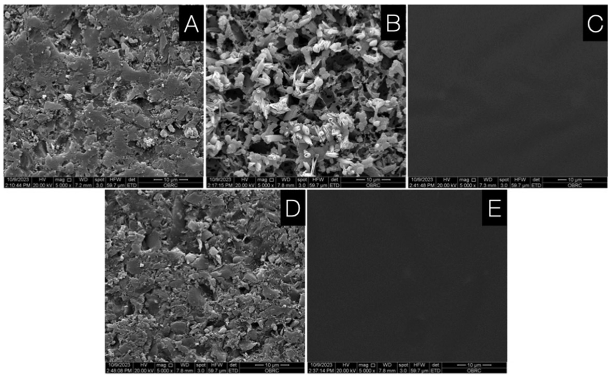

Figure 3: Representative SEM images after surface treatment at 5000X magnification. (A), Surface of aged PICNs presented roughness and narrow valley: (B), Aged PICNs, treated with 9.5% hydrofluoric acid and silane, exhibited numerous microporosities between the intact polymer phase: (C), Aged PICNs, treated with 9.5% hydrofluoric acid and silane followed by resin monomer application, revealed a flat and smooth surface: (D), Aged PICNs, treated with a self-etching ceramic primer, displayed slight surface roughness: (E), Aged PICNs treated with a self-etching ceramic primer followed by resin monomer application showed a smooth surface.

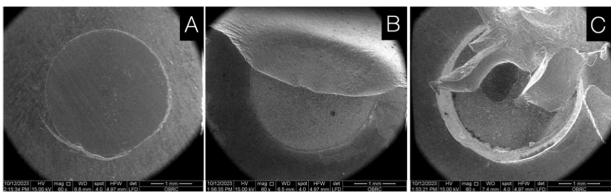

Figure 4: Representative SEM images of specimens after the shear bond strength test reveal different failure modes. (A), Adhesive failure, all the failure occurred only at the materials interface: (B), Mixed failure, partial fracture of the interface was shown and involved in PICNs: (C), Mixed failure, partial fracture at the interface was shown and involved in resin composite.

monomer in the PICNs and the resin-based materials. Additionally, this phase is resistant to hydrofluoric acid as it remained intact shown in Figure 3B, forming etching pattern that effectively facilitate bonding. Therefore, this micromechanical interlocking can be concluded that it has an even greater influence on the adhesive interface's performance compared to chemical reaction.[26]

The creation of sufficient space following glassy dissolution is essential for enhancing surface wettability and ensuring secure micromechanical interlocking between PICNs and resin-based materials. Unlike the HF+Si group, the porosities on PICNs treated with a self-etching ceramic primer (Group MEP) presented minimal surface modification, resembling the untreated surface as seen in Figure 3A and 3D. The main active ingredient in a self-etching ceramic primer responsible for glass-ceramic dissolution is Tetrabutylammonium dihydrogen trifluoride (TADF), which has lower acidic aggressiveness compared to hydrofluoric acid. Due to this milder etching effect, the removal of the glassy phase is limited, resulting in lower surface roughness, as reported in a previous study.[29] The small spaces created by this treatment may hinder the penetration of conventional resin composites, which are highly viscous. This limitation likely explains the significantly lower shear bond strength (SBS) observed in PICNs treated with MEP alone, which was consistent with previous studies showing that ceramic materials treated with MEP exhibited a lower bond strength compared to those treated with HF and silane.[16,30,31]

Numerous studies proposed applying hydrophobic resin monomer coating on silanated ceramic surfaces before repairing them with resin composite to improve the bond between resin composite and ceramic interface.[19,20] The viscosity of hydrophobic resin monomer was less than that of resin composite, providing improved flowability on silanated ceramic surface, filling in small pores and irregularities on surface, resulting in a close adaptation and preventing any defects.[19,20] In recent years, universal adhesives containing silane applied on etched ceramic surfaces have been introduced, claiming their simplified application procedure and fewer clinical steps.[32] However, various studies observed a negative effect on bond durability when multicomponent ceramic primers or bonding agents containing hydrophilic monomers were used to repair ceramic.[4,32-34] A previous study demonstrated that the hydrophilic component in dental adhesive applied to silanated feldspathic ceramics led to a decrease in microtensile bond strength over time, despite initially high values.[33] Therefore, the low-viscosity, hydrophobic resin, Heliobond, which lacks hydrophilic components, was chosen as an adjunctive surface treatment before repairing the aged PICNs.

The results from HF+Si+He group showed no significant difference from the HF+Si group, indicating that the hydrophobic resin monomer was not necessary for surface treatment of aged PICNs in the scenario when PICNs was treated with HF and silane. This can be explained by the distinctly greater surface roughness on PICNs.[28] The deep and large valley on the PICNs surface may allow the viscous resin composite to adapt closely to the prepared surface, even without a low-viscosity hydrophobic resin layer. However, recent study was reported that the application of a universal adhesive can achieve similar SBS in HF-treated ceramic, despite no additional silane application.[35] Therefore, when conventional hydrofluoric acid was used as a surface treatment, the necessity of an additional hydrophobic coating in ceramic repair remained inconclusive and was required further study.

A self-etching ceramic primer contains not only TADF but also silanes as a single-component system, designed to simultaneously promote siloxane activity on the prepared surface in one application.[16,24,36] However, the acidic nature of the MEP solution raised concerns about the hydrolytic stability of organosilane, potentially reducing its effectiveness.[37] In addition to acidity, rinsing the surface with water after allowing the solution to react may interfere with silanol activity. Despite these concerns, the silane in MEP has been reported to retain silanol activity after immersion in hot water or thermocycling, as demonstrated using micro MIR-FTIR.[29] This stability was likely attributed to the specific component bis(triethoxysilyl) ethane (BTSE), which is more hydrophobic due to the presence of an ethane group in its structure.[38] BTSE enhanced hydrolytic stability and facilitated the effective performance of organosilane.[39] The results from MEP+He group in the present study also proved the retained activity of silane. The low-viscosity hydrophobic resin was able to flow intimately into the material structure, effectively wetting the MEP-treated surface and creating a well-prepared bonding interface for copolymerization with conventional resin composite materials. This led to SBS values from this group comparable to the HF+Si group, indicating the potential of MEP+He in adhesive performance for repairing aged PICNs.

The composition of the additional resin layer should also be considered. Fillers in adhesive agents enhanced mechanical properties[40,41], probably improving bond between the adhesive and the ceramic substrate. However, an increase in filler size and volume raised viscosity[40,41], negatively affecting wettability and limiting resin penetration into micro-porosities, which may compromise bond strength. Therefore, further studies are needed to investigate the impact of filler composition on the bond strength of repaired PICNs.

When compared to a newly restored material, aged material exhibited a significant decrease in bonding performance.[16,18] Thermocycling is the most commonly used method for accelerating aging simulation, particularly for assessing the thermal effect on the bond interface, which could induce material fatigue due to thermal fluctuations.[15,23,24,26,42-44] Several studies have reported differences in bond strength between immediate and 5000-thermocycled PICNs.[42,45] Additionally, a clinical study indicated that the first instance of chipping in PICNs restoration was observed approximately 11.4 months post-insertion.[11] To simulate intraoral condition for one year[11], 10,000 thermal cycles were performed. The incompatibility of the thermal expansion coefficients of different materials may lead to failure in repaired restorations. Moreover, decrease in bond strength values observed after thermocycling could be attributed to water exposure, which negatively affects polymer stability, resulting in resin composite plasticization and, ultimately, hydrolytic degradation.[42] In contrast with the *in vitro* study, oral environmental conditions affected wear and degradation of dental restorations.[46,47] Moisture degraded the siloxane bond, resulting in silane hydrolysis and deteriorating the bond over time.[42,47,48] Therefore, a combination of different accelerating aging processes is suggested for further study.

The difference in mechanical properties between repaired ceramic restorations and the less-stiff resin composite used at the fracture site can generate high tensile stresses at the ceramic-composite interface beneath the loaded area.[46] Therefore, further clinical studies are needed to evaluate the long-term survival of repaired restorations. Additionally, newly developed resin composites, which claim to have higher strength than previous formulations, should be investigated for their potential in repairing hybrid ceramic materials.

Conclusions

Aged PICNs can be effectively repaired using either hydrofluoric acid and silane or a self-etching ceramic primer followed by the application of a hydrophobic resin. However, surface treatment with a self-etching ceramic primer alone may be insufficient for achieving optimal repair of aged PICNs.

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Conflicts of Interest

The authors declare no conflict of interest.

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Case Report

A Delayed Onset Cyst-like Lesion at the Lip after Hyaluronic Acid Filler Injection: A Case Report

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Abstract

Nowadays, lip augmentation has become a key component in addressing cosmetic concerns. In particular, hyaluronic acid (HA) fillers are increasingly used for this minimally invasive procedure. Generally, this procedure is well-tolerated, and major adverse events are rare. However, some delayed complications can occur following HA filler injection. Here, we report a case of a HA-related complication in a 45-year-old female patient, affecting the lower lip. Four weeks after the HA filler application, without any immediate adverse effects, a painless, well-defined border nodule occurred in the wet lip area. This cyst-like lesion was surgically identified and successfully treated with surgical excision. Clinicians should be aware that a case manifesting as a well-defined lip nodule suggests salivary gland cysts, soft tissue tumors and cysts, as well as filler-related nodules. This delayed presentation of HA-related nodule in the lower lip poses unique diagnostic and management challenges.

Keywords: filler, filler complication, hyaluronic acid, lip, mucocele

Introduction

In recent decades, lip augmentation procedures have been developed to address the growing trend of achieving ideal lips and combating signs of aging. Among the various methods available, filler injections have emerged as one of the most common and effective approaches.[1] The evolution of fillers has been remarkable, beginning with bovine collagen injections in the 1980s and progressing to include human collagen, hyaluronic acid (HA), calcium hydroxyapatite, poly-L-lactic acid, silicone, and other formulations.[2,3] The ideal skin filler is expected to offer several essential characteristics. It should be biocompatible, allowing for seamless integration with the body's tissues. Moreover, it should be removable when necessary, cost-effective, hypoallergenic, have a long-lasting effect, and easy to distribute and store. In the current landscape of cosmetic procedures, HA dermal fillers stand out as a preferred choice due to their ability to meet many of these criteria. HA, regardless of its source–be it from animals, humans, or HA-producing bacteria–possesses the same molecular structure, thereby minimizing the risk of allergic or immunogenic reactions. This lack of tissue or species specificity enhances its safety profile.[2,3] However, the rapid breakdown of original HA by hyaluronidase poses a challenge, as it has a short half-life of only 12 hours. To address this limitation, manufacturers have developed injectable HA skin fillers with enhanced longevity and durability by modifying the cross-linking chain of HA.[2,4] These advancements have significantly extended the duration of HA fillers, allowing patients to enjoy their aesthetic benefits for longer periods with fewer maintenance treatments

Mild pain, erythema, swelling, and bruising at the injection site are common complaints after HA injection.[2] While these symptoms are typical and generally subsided within a short period, the procedure itself is associated with a very low rate of serious complications.[5] One such severe complication, well-documented in medical literature, is blindness, which occurs when the filler is inadvertently injected into vessels around the orbits, such as the supraorbital vessels. The high pressure at the needle's end, coupled with a bolus injection technique, can cause the product to flow backward into the ophthalmic artery, leading to central retinal artery occlusion. Additionally, other uncommon yet significant complications can arise, including vascular infarction, skin necrosis, hypersensitivity reactions, cellulitis, abscess formation, as well as nodules and granulomas. Nodule formation, in particular, presents an intriguing challenge for clinicians. These nodules may manifest as early or delayed onset, with delayed cases occurring more than 4 weeks post-injection.[6] While early nodules are relatively well-documented and managed, delayed onset nodules remain less frequently reported in medical literature.

Our case report focuses on one such instance–a delayed-onset cystic-like complication related to HA filler injection in the lower lip. This delayed presentation of a cystic-like nodule in the lower lip poses unique diagnostic and management challenges. Comprehending the effects of lip augmentation with HA fillers may enables clinicians to administer safe and effective outcomes.

Case Report

We present the case of a healthy 45-year-old woman who received an application of HA on her lower lip at a local esthetic clinic. Even though IRB review is not required, this case report was prepared in accordance with the requirements of the HIPAA regulations. Four weeks after the HA filler application, without any immediate adverse effects, a painless nodule occurred at the wet zone of the lower lip opposite to teeth 32 and 33. The patient did not know the brand of the filler. She denied having lip sucking or biting habits. The lesion was a submucosal cyst-like nodule with a diameter of a centimeter (Figure 1). The patient was treated at the local clinic by hyaluronidase injection a month after the appearance of the lesion, but the lesion did not subside. Three months later, she came to our hospital reporting no change in the size of the lesion. The differential diagnosis was made: mucocele or delayed onset filler nodule. After a discussion with the patient, we decided on treatment by surgical excision of the mass under local anesthesia. The incision was made at the wet area of the lower lip, approximating to the lesion, and the mucosal flap was elevated to explore the lesion. At this point, there was a 3-millimeter dense nodule close to the swelling mucosa (Figure 2). Approximately half a cc of content was found surrounding the dense nodule. The gross feature of the semi-liquid content was translucent, gel-like substance. It is slightly cloudy in appearance and has a viscous texture (Figure 3). The nodule and HA filler-like substance were surgically removed, and the wound was closed after copious irrigation. Unfortunately, the patient strongly declined a pathological examination of the lesion due to economic reasons.

At a month of follow-up, the lesion was grossly cured. The lip was symmetrical without swelling. The scar from surgical excision was placed on the wet lip, which was hardly visible during smiling or speaking (Figure 4).

Figure 1: A nodule at the lower lip opposite to teeth 32 and 33. The lesion was a submucosal cyst-like nodule with a diameter of a centimeter.

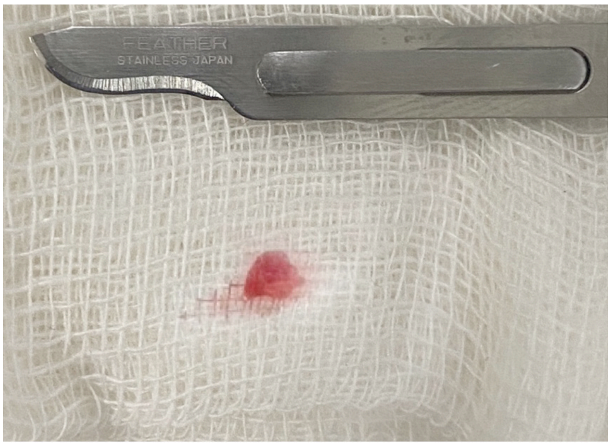

Figure 2: A 3-millimeter dense nodule was surgically removal.

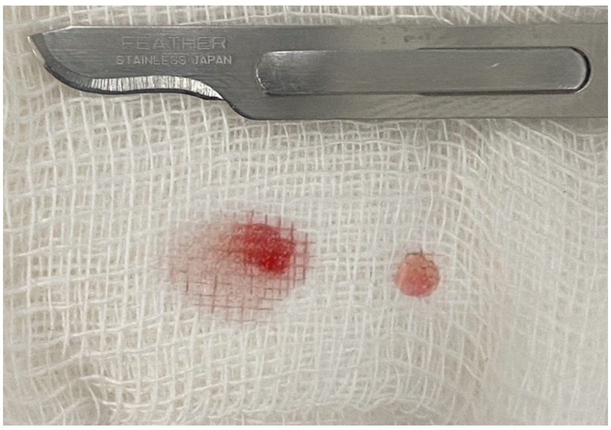

Figure 3: Approximately a half of a cc of HA filler was found underneath the dense nodule.

Figure 4: At a month of follow-up, the lesion was cured. The lip was symmetrical without swelling.

Discussion

Lips, in particular, have historically been a significant feature of the face, contributing to overall attractiveness and a youthful appearance. The lower lip lies between the mouth and the mentolabial sulcus. The sharp demarcation between the colored edge of the lip and surrounding skin is called the vermillion border. The vermillion is a transition layer between the outer, hair-bearing tissue and the inner mucous membrane. The skin of the vermillion is made up of three to five cellular layers and is much thinner compared to the skin on the rest of the face.[7,8] Therefore, lip augmentation procedures aimed at enhancing fullness and promoting a youthful look are frequently sought after in aesthetic medicine. Lip enhancement techniques are classified into surgical and nonsurgical procedures.[1-3] One surgical procedure, the triple V-Y augmentation technique[9], is performed without the use of dermal fillers or implants and aims to expand the vermilion by advancing the labial mucosa forward. Other surgical options for lip augmentation exist as well.[10] Surgical lip implants and autologous fat transfer are used only rarely.[11]

The injection of dermal fillers is the most popular nonsurgical procedure performed to increase the volume and improve the shape of the lips.[12] Semi-permanent dermal fillers–such as calcium hydroxyapatite and poly-L-lactic acid–and permanent fillers are not preferred for lip augmentation because they have an increased risk of irregularity and nodule formation. Hyaluronic acid filler is one of the most commonly used products for lip enhancement.11 HA injections are generally safe with a very low risk of severe adverse reactions, though complications such as skin necrosis, infection, allergic reactions, visual impairment, and nodules or granulomas can occur. Based on a review of lip complication in 17 reported cases,[13] nodules may develop early or delayed after injection, with an incidence of 0.1 to 1.0%. When the HA nodule occurred at more than 4 weeks, the nodule is diagnosed as delayed type.[6] These nodules can be inflammatory, resulting from the body's foreign-body response, or non-inflammatory, typically caused by improper filler placement. Inflammatory nodules may appear days to years after injection, while noninflammatory ones often appear immediately. HA is typically temporary and resorbable, minimizing foreign-body effects, accordingly many non-inflammatory nodules resolve with observation, massage, or hyaluronidase.[5,6]

However, diagnosing lip nodules can be challenging since patients may not report their history of filler injections, which could have been performed weeks, months, or even years prior. A broad range of potential diagnoses commonly includes abscesses, sialadenitis, mucocele, benign salivary gland neoplasms, or malignancy.[14,15] Infections can present early or late in the clinical course and are more commonly associated with single nodules. Involvement of multiple sites suggests a foreign-body granulomatous response more likely. Cases presenting as well-defined lip nodules suggest salivary gland tumors or cysts, such as mucoceles, as well as soft tissue tumors and cysts. Timely and accurate diagnosis of these masses is crucial, as they may mimic neoplasms, which is particularly important given the generally older age group of these patients. Differential diagnoses were summarized in the table 1.

In 2020, Phillip-Dormston[6] provided the management of delayed-onset nodules caused by HA filler. For the inflammatory group, the management starts with non-steroidal anti-inflammatory drugs combined with anti-histamines and antibiotics, hyaluronidase, intralesional steroid injection, intralesional laser, and intralesional radiofrequency. If an abscess or fluctuation is present, surgical intervention with incision and drainage may be required for resolution. For non-inflammatory nodules, small or inconspicuous lesions can often be managed conservatively with observation. Hyaluronidase can be administered when the lesion is visible. This guideline was developed for filler-related HA nodules, but in our patient, the lesion was differentially diagnosed as mucocele and an HA-related nodule. We decided on treatment by excision and filler evacuation. A key limitation of this report is the absence of pathological confirmation. However, the author posits that the lesion likely originates from HA filler, based on its distinct gross features and the patient's history of HA filler injection in the affected area.

Conclusions

Practitioners should be aware that a case manifesting as a well-defined lip nodule suggests salivary gland cysts, soft tissue tumors and cysts, as well as filler-related nodules. This delayed presentation of HA related nodule in the lower lip poses unique diagnostic and management

Table 1: A summary of differential diagnoses for cystic-like lesions and related lesions at the lips.

Condition	Key features	Clinical presentation	Treatment
Abscess	Infection, localized swelling, redness, warmth, and/or pain	Single nodule, tenderness, history of trauma or infection	May require surgical drainage
Sialadenitis	A form of inflammation of salivary gland, often due to obstruction	Lip swelling with pain, sometimes the patient has fever	Antibiotics, Drainage rarely needed
Mucocele	Cystic lesion with fluid-filled, caused by a blockage of duct or tear of the gland	Soft, bluish nodule; often associated with trauma (e.g., lip biting, bracket irritation)	Surgical removal
Benign tumor	Non cancerous lesion included benign of salivary gland, lipoma or fibroma	Firm and painless nodule with slow growing	Excision
Malignancy	Hard, fixed nodule, irregular borders, lymphadenopathy	Rapidly growing, painful, with possible ulceration or bleeding	Urgent biopsy for a diagnosis
Hyaluronic acid filler Nodule	Its distinct features and the patient's history of HA filler injection	Well defined, firm and non tender	Observation, massage, hyaluronidase injection; if unresolved, surgical removal

challenges. Despite its rarity, understanding and recognizing such complications are essential for providing optimal patient care and ensuring timely intervention to mitigate potential adverse outcomes.

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Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT-4 to refine and correct certain parts of the English grammar. After using this tool the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Review Article

Glass Hybrid Glass Ionomer Restorative Materials: A Literature Review

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Abstract

The emergence of glass hybrid glass ionomers (GH-GICs) represents a significant innovation in restorative dentistry, addressing the limitations of traditional materials through enhanced mechanical strength, fluoride release, and ease of application. Given the absence of prior comprehensive literature reviews on this topic, this systematic review was conducted to provide general practitioners with essential insights. A comprehensive literature search was performed in the PubMed, Scopus, and Web of Science databases from 2010-2023, using terms related to GH-GICs, their properties, and their clinical performance. The studies included were published in English and included *in vitro* and *in vivo* research as well as randomized controlled trials. Compared with conventional glass ionomers, GH-GICs exhibit improved mechanical properties, fluoride release, and remineralization potential, showing clinical performance comparable to that of resin composites in small to moderate class I and class II posterior restorations. However, limitations such as marginal adaptation, surface wear, and reduced aesthetics persist, particularly in larger restorations. While resin coatings improve initial wear resistance, their limited longevity and reduced fluoride release present additional concerns. GH-GICs remain promising for specific clinical scenarios, especially in high-caries-risk, pediatric, and geriatric patients, but further long-term studies are needed to confirm their efficacy fully and extend their applications.

Keywords: bulk-fill, glass hybrid, glass ionomers, high viscosity, restorative dentistry

Introduction

Resin composites are highly desirable for their aesthetic and physical qualities but are hindered by the time-consuming technique needed, particularly in deep cavities.(1) To simplify procedures and save time, bulk-fill materials such as bulk-fill resin composites and high-viscosity glass ionomer cements (HV-GICs) have been developed.(2,3) Bulk-fill resin composites offer a promising, time-efficient alternative to conventional resin composites for posterior restorations. Nevertheless, further long-term randomized clinical trials are needed to fully validate their clinical effectiveness.(1,2,4)

Recently, HV-GICs have gained attention as bulk-fill materials, combining the benefits of conventional low-viscosity glass ionomer cements with improved handling properties and mechanical strength. The latest advancement in HV-GICs is the introduction of glass hybrid glass ionomer cements (GH-GICs), which are being promoted for broader clinical applicability. This paper reviews the literature on GH-GICs, focusing on their properties, applications, and clinical implications in restoring permanent teeth.

Search strategy and inclusion criteria

A systematic literature search was conducted to identify relevant studies on GH-GICs. The search was performed via electronic databases such as PubMed, Scopus, and Web of Science, with search terms including "glass hybrid glass ionomer," "high-viscosity glass ionomer," "bulk-fill," "restorative dentistry," "Equia Forte," "Equia," "mechanical properties," "clinical performance," and "fluoride release." Boolean operators (AND, OR) were used to refine the search. Studies published in english from 2010-2024 that focused on the properties, clinical applications, and performance of GH-GICs, as well as comparisons with other restorative materials, were included. Both *in vitro* and *in vivo* studies, including randomized controlled trials and laboratory studies, were considered. Duplicates were removed, and articles were screened on the basis of titles, abstracts, and full-text reviews. The reference lists of the selected articles were also examined to ensure comprehensive coverage of the relevant literature.

Results of the literature search

High viscosity glass ionomers

During the 1990s, industry coined the term 'high viscosity glass ionomer cement' to describe improved glass ionomer cement (GIC).(5) These materials contain high-molecular-weight polyacrylic acid and surface-modified fillers, which increase their reactivity and produce high cross-linkages in the set matrix.(6) Additionally, they are mixed in a higher powder–liquid ratio than conventional GICs are, increasing their performance.(7,8)

HV-GICs exhibit superior physical and mechanical properties, particularly in terms of wear resistance, along with a faster setting time, enabling restorations to be completed in a single visit. Compared with their conventional counterparts, they possess a more translucent appearance due to the inclusion of fine glass particles.(7,9) The enhanced attributes of HV-GICs broaden their applications,(6,10-14) making them versatile for various clinical applications where resin composites and amalgams might not perform optimally.(15-24)

Microlaminated GICs have been introduced to widen the indications for using HV-GICs in the posterior region, where HV-GICs are combined with a light-cured coating. In 2007, the Equia restorative system (GC America, Alsip, IL, USA), comprising Equia Fil–a self-adhesive bulk-fill HV-GIC–and Equia Coat–a highly nanofilled light-cured resin coating–was introduced. Equia Fil, was optimized by the manufacturer to enhance cross-linkage within the GIC matrix. Paired with the Equia Coat, it was promoted as a suitable restorative material for posterior stress-bearing restorations.

The clinical performance of high-viscosity glass ionomers

Studies investigating the clinical performance of HV-GICs have demonstrated satisfactory performance in class I(24,26-30) and small-to-medium class II restorations,(9,27,30-32) with some studies recommending limiting the size of medium class II cavities to ensure that they do not exceed half the intercuspal width in the isthmus width.(33) Klinke *et al.,*(30) compared the clinical effectiveness of the Equia system to that of the conventional Fuji IX GP Fast (GC, Tokyo, Japan) coated with Fuji Coat LC (GC, Tokyo, Japan) on permanent posterior teeth in both class I and class II (two and three surfaces) cavities over a 4-year observation period. The results indicated comparable performance between the two materials in class I cavities. However, in class II fillings, the Equia restorative system displayed superior overall performance, with fewer failures observed during follow-up evaluations. Türkün

Table 1: Lists the HV-GIC products currently available on the market.

Product	Coat*	Manufacturer	Notes
-GC Fuji IX GP -GC Fuji IX GP Fast -GC Fuji IX GP Extra	G-Coat Plus (light cure 20 sec), GC Fuji Coat LC (light cure 10 sec), or GC Fuji Varnish (blow dry)	GC, Tokyo, Japan	Fuji IX GP Fast is the fast setting version of Fuji IX GP. This product achieves its initial set in only 3 minutes and 35 seconds after mixing; final finishing can begin in only 3 minutes after placement. Fuji IX GP Extra: This product contains a next generation glass filler which elicits higher translucency, fluoride release, reactivity and a faster setting time. It allows final finishing in only 2.5 minutes from initial mix.
-Riva Self Cure (Regular) -Riva Self Cure (Fast) -Riva Self Cure HV	Riva Coat (light cure resin coating)	SDI, Victoria, Australia	Riva Self Cure HV has a higher powder/liquid ratio (0.50/0.12 g) compared to the other two variants (0.42/0.12 g)
-Ketac Universal Aplicap -Ketac Molar Aplicap	Ketac Glaze (mainly for Ketac Molar Aplicap)	3M ESPE, Seefeld, Germany	Ketac Universal Aplicap is a user-friendly, versatile glass ionomer for quick, less demanding restorations, while Ketac Molar Aplicap is a tougher, packable choice for durable posterior restorations prioritizing strength over aesthetics or speed.
-Chemfil Rock	Surface protection recommended (e.g., resin-based coating or varnish)	Dentsply, Milford, USA	It uses a novel reactive zinc-modified fluoro-alumino-silicate glass filler
-Equia Fil	Equia Coat (A nanofilled, light-cured resin coating)	GC America, Alsip, IL, USA	In some markets, Equia Fil is sold as Fuji IX GP Extra and Equia Coat as G-Coat Plus.[14,25] The primary difference is that Equia Fil is Fuji IX GP EXTRA packaged within the Equia system, designed to be used with Equia Coat for enhanced properties, whereas Fuji IX GP EXTRA is the standalone GIC that doesn't require the coating.
-Gold label IX Extra Capsule -Gold label IX Extra	G-Coat Plus, GC Fuji Coat LC, or GC Fuji Varnish	GC America, Alsip, IL, USA	The Fuji IX GP EXTRA and Gold Label IX Extra are actually the exact same product — just branded differently depending on the market or region

*Although these materials can technically be used without a final coat, coating is strongly recommended to enhance wear resistance, surface hardness, and longevity.

and Kanik[33] conducted a six-year assessment of the long-term clinical efficacy of Equia Fil and Riva Self Cure (SDI, Victoria, Australia) both of which were coated with Equia Coat and a classical varnish (Fuji Varnish). Equia Fil exhibited acceptable clinical performance in class I restorations and moderate to large class II restorations over six years.

However, the clinical performance of the conventional GIC (Riva Self Cure) in moderate to large class II restorations was notably inferior to that of Equia Fil. Equia Fil demonstrated superior performance to Riva Self Cure in terms of anatomic form, color match, marginal adaptation, and retention rate throughout the evaluation period. Notably, both coatings applied to all the restorations were worn away after six months. Heck *et al.,*[32] conducted a long-term study over six years to assess the performance of two HV-GIC systems, the Fuji IX GP Fast/Fuji Coat LC and Equia Fil/Equia Coat restoration systems, which were applied as definitive restorations for class II cavities for permanent dentition. Both materials demonstrated acceptable and comparable survival rates, indicating their suitability for smaller class II cavities. Over the six years, both Equia Fil and Fuji IX GP Fast restorations showed significant deterioration in surface luster, marginal adaptation, material fracture, and retention, with no notable differences observed between the two materials. Hatirli *et al.,*[24] compared the two-year clinical outcomes of HV-GICs and nanohybrid resin composite restorations (GrandioSO, Voco). HV-GICs demonstrated comparable clinical performance to resin composite materials. HV-GICs presented lower marginal discolouration, greater surface wear and loss of anatomic form. The resin composite had a significantly better surface luster. Rożniatowski *et al.,*[31] conducted a clinical and radiological assessment comparing the Equia restorative system and resin composite material (Tetric EvoCeram, Ivoclar Vivadent). Their findings suggested that the resin composite and Equia systems exhibited similar efficacy over a 2-year observation period when used to restore approximal lesions in premolars and permanent molars. However, it is important to note that when HV-GICs were utilized, there was a greater risk of marginal adaptation deterioration, staining, and erosion. Uzel *et al.,*[27] compared the clinical performance of the Equia system on class I and II cavities with that of a bulk-fill resin composite (Tetric EvoCeram, Ivoclar, Vivadent) over 24 months in young adults. Both materials displayed good clinical performance. However, Equia showed more common chipping and surface degradation over the two years.

In summary, HV-GICs have proven to be effective restorative materials for class I and small-to-medium class II cavities, with specific materials such as Equia Fil often outperforming conventional GICs in terms of anatomic form, color match, and retention. While HV-GICs demonstrate comparable performance to resin composites in terms of retention and marginal discoloration, they face challenges in larger restorations, including marginal deterioration, surface wear, and reduced aesthetic performance. In contrast, the resin composites maintain better surface luster over time.

Glass hybrid glass ionomers

In 2015, Equia Forte (GC America, Alsip, IL, USA) was introduced as an innovative restorative system utilizing glass-hybrid technology. The system builds on the performance of the original Equia restorative line and comprises Equia Forte Fil and its corresponding light-cured surface sealant, Equia Forte Coat. Equia Forte Fil is a self-adhesive bulk-fill restorative material based on an enhanced GIC structure. It incorporates ultrafine, highly reactive fluoroaluminosilicate glass particles with a bimodal size distribution–a combination of larger conventional glass fillers and smaller, highly reactive nanofillers–improving the packing density and reactivity. These particles facilitate rapid ion release and robust matrix formation. The liquid component consists of a higher molecular weight polyacrylic acid combined with water and tartaric acid, which enhances handling and working time. Compared with traditional HV-GICs, this glass hybrid formulation results in improved ion availability, leading to enhanced cross-linking, a stronger glass-ionomer matrix, and superior flexural strength.[34] The system also includes Equia Forte Coat, a nanofilled, light-cured resin coating that contains a novel multifunctional methacrylate monomer. The manufacturer claims that this coating forms a dense, wear-resistant resin matrix that seals the surface, enhances aesthetics, and protects the restoration from early moisture contamination and dehydration.

In 2019, the Equia Forte HT (High Translucency) restorative system was launched, featuring an optimized formulation that offers improved translucency and aesthetics. Equia Forte HT maintains the same core glass hybrid structure but utilizes a refined and narrower particle size distribution, further enhancing handling properties and mechanical performance. Table 2 lists the GH-GICs products currently available on the market.

Mechanical properties

As restorative materials, GH-GICs must demonstrate adequate mechanical performance to replace missing tooth structures. Studies comparing GH-GICs to HV-GICs and resin composites have shown that GH-GICs, particularly Equia Forte and Equia Forte HT, exhibit comparable or slightly superior mechanical pro-

Table 2: GH-GICs products currently available on the market.

Product	Coat	Manufacturer	Notes
Equia Forte Fil	Equia Forte Coat	GC America, Alsip, IL, USA	
Equia Forte HT	Equia Forte Coat	GC America, Alsip, IL, USA	
Gold Label Hybrid	G-Coat Plus (light cure) or GC Fuji Varnish (blow dry)	GC America, Alsip, IL, USA	Available only in a hand mixed version

perties to HV-GICs, particularly when the Equia Forte Coat is applied.[34-40] The protective coating plays a critical role in maximizing the performance and surface durability. Fuhrmann *et al.,*[37] found that while fracture toughness was similar among GICs, the application of Equia Forte Coats significantly increased surface hardness, reaching levels comparable to those of resin composites such as Filtek Z250 and even exceeding those of Filtek Supreme Ultra. Similarly, Brkanović *et al.,*[8] reported that Equia Forte HT, both coated and uncoated, outperformed Fuji IX GP in terms of wear resistance, with coated samples showing notably greater durability.

However, despite these improvements, certain drawbacks persist. Voids may form during placement, particularly in hand-mixed versions, compromising the internal integrity of the material.[41-43] Cohesive failures have also been reported under functional loading, especially in larger restorations.[40,44] These failures highlight the intrinsic limitations in fracture toughness and fatigue resistance of GH-GICs. Notably, recent studies have consistently reported that these failures are often cohesive in nature–occurring within the material itself–while the bond to tooth structure remains intact.[45]

However, GH-GICs still lack resin composites in terms of key mechanical properties, such as compressive strength, fracture toughness, and surface hardness.[34,35,40] This is mainly due to the superior micromechanical bonding of resin composites, as well as their inherently higher material strength. Kutuk *et al.,*[46] compared Equia Forte to a microhybrid resin composite (G-ænial Posterior) and reported no significant difference in fracture resistance but significantly greater compressive strength in the resin composite. Valeri *et al.,*[47] noted that while resin composites such as Filtek Supreme Ultra showed superior wear resistance, Equia Forte HT–particularly when coated–demonstrated a substantial reduction in wear, highlighting the importance of the resin coating in enhancing clinical durability.

In addition to mechanical improvements, advancements in glass-hybrid technology have led to notable enhancements in the optical properties of GH-GICs. The introduction of Equia Forte HT marked a significant step forward in improving translucency, an essential factor for aesthetic integration with natural dentition. This improvement is attributed to the optimized particle size distribution, which allows the material to blend more harmoniously with the surrounding tooth structure. Studies comparing the optical properties of GH-GICs and resin composites have revealed mixed findings. Yeo *et al.,*[38] evaluated materials such as Equia Forte, Fuji IX, Filtek Z350, and Filtek One Bulk Fill and reported that resin composites presented significantly higher translucency levels than did GH-GICs. In contrast, Moshaverinia *et al.,*[39] found that Equia Forte HT outperformed Fuji IX and ChemFil Rock in translucency. Despite these advancements, resin composites remain the preferred choice for highly aesthetic restorations because of their superior ability to achieve high translucency and natural blending.

Resin coating

The application of a resin coating, such as Equia Forte Coat, is essential during the early maturation phase of GH-GICs.[48,49] This coating serves as a temporary barrier protecting the GIC from moisture imbalances during its initial setting phase (6 to 12 months). Resin coatings have been shown to improve surface hardness, flexural strength, surface roughness, and initial wear resistance.[48,49] Kanik *et al.,*[50] noted that resin coatings render GH-GICs wear resistant over extended durations, comparable to resin composites. Habib *et al.,*[51] found that coated GICs presented significantly greater flexural strength, reduced surface roughness, and improved marginal integrity. Fuhrmann *et al.,*[37] and Handoko *et al.,*[52] also reported significant increases in surface hardness with the application of resin coatings. Additionally, Jafarpour *et al.,*[53] demonstrated that resin coatings reduce water sorption and solubility, stabilizing the physical properties of the material.

Despite these benefits, resin coatings do not uniformly enhance all mechanical properties. For example, fracture toughness and elastic modulus remain largely unaffected, with some studies even suggesting that uncoated samples may exhibit higher elastic moduli.[37,38] Ong *et al.,*[54] concluded that the resin coating did not enhance the viscoelastic properties and was unnecessary for improving the elastic performance. Furthermore, the long-term effectiveness of resin coatings in achieving adequate wear resistance remains uncertain.[8,47,49,55]

In summary, GH-GICs, particularly Equia Forte and Equia Forte HT, represent significant advancements over traditional GICs, offering improved mechanical, optical, and biological properties. The application of resin coatings further enhances surface hardness and initial wear resistance, although their long-term effectiveness is limited. While GH-GICs outperform earlier GIC generations and are well suited for low-stress restorations, they still fall short of resin composites in key areas, such as compressive strength, fracture toughness, and translucency. However, their ease of use, cost-effectiveness, and caries-preventive properties make them valuable options for high-caries-risk patients and pediatric and geriatric populations. Future research should focus on developing more durable protective coatings and innovative formulations to increase the long-term performance of GH-GICs and bridge the gap with resin composites, expanding their role in modern restorative dentistry.

Properties of the fluoride release and remineralization of GH-GICs

GH-GICs retain the favorable biological properties of conventional GICs, including chemical bonding to the tooth structure, biocompatibility, and sustained fluoride release. Fluoride release is a hallmark of GH-GICs, offering both immediate and long-term caries prevention. The burst effect involves rapid fluoride release shortly after placement, providing an initial anticariogenic boost. This is followed by a sustained reservoir effect, where the material absorbs and rereleases fluoride over time, enhancing long-term protection.(56) The release of fluoride from GH-GICs contributes to the formation of fluorapatite, enhancing remineralization and inhibiting caries progression.(56,57) Studies indicate that Equia Forte can induce remineralization in carious dentine up to a depth of 2 mm.(58) Zebić *et al.,*(59) compared the fluoride release from three different GICs. They reported that Equia Forte released more fluoride than Fuji IX and Fuji II, which had the lowest fluoride concentration among the tested GICs. Moshaverinia *et al.,*(34) evaluated the fluoride release of three HV-GICs (Equia Forte Fil, Fuji IX, and Chemfil Rock). They reported that all the examined materials exhibited comparable initial fluoride-releasing properties, whereas Equia Forte Fil exhibited significantly greater amounts of fluoride release from the bulk of the material after 4 weeks. Similarly, another study reported that Equia Forte HT also exhibited superior fluoride-releasing capacity compared with Fuji IX GP and Chemfil Rock, further highlighting its potential role in preventing caries.(39)

However, applying a resin coating, while enhancing the mechanical properties and wear resistance of GH-GICs, presents a trade-off by reducing fluoride release. This reduction is attributed to the resin-based nature of the coating and the presence of nanofillers, which seal the microgaps in the material, thereby limiting the diffusion of fluoride ions.(60-63) As not all mechanical properties are consistently improved and the long-term benefits for wear resistance remain uncertain, the use of a resin coating should be considered selectively.(64) In clinical situations where sustained fluoride release and remineralization are important, its application may warrant careful reconsideration.(61)

Bonding to the tooth structure

Equia Forte, a GH-GIC, has demonstrated improved bond strength compared with its predecessor, Equia Fil, and other conventional HV-GICs. Studies have shown that Equia Forte has a relatively high shear bond strength (SBS) to enamel and dentin. Karadas *et al.,*(65) evaluated the SBS and adaptation at the interface between various capping materials (Biodentine), TheraCal LC, Ultrablend Plus, Calcimol LC, ApaCal ART, Ionoseal, Equia Forte and dentin. Compared with the other materials, Equia Forte presented significantly greater SBS. Despite their high viscosity, self-curing materials such as Biodentine and Equia Forte displayed superior adaptation to dentin compared with light-cured materials. Latta *et al.,*(66) reported that Equia Forte and Fuji II LC had comparable SBS and shear fatigue strength (SFS) values, both of which were significantly lower than those of the resin composite (Z100 Restorative) bonded with a universal adhesive (Prime&Bond Active). The resin composite provided superior bond durability, particularly to enamel and dentin, whereas Equia Forte and Fuji II LC showed similar clinical effectiveness in bonding to enamel and dentine.

The use of a dentin conditioner–commonly polyacrylic acid–is an optional but recommended step to increase the bond strength of GICs.(67) Research indicates that both the type of conditioner and the duration of its application can significantly impact bond strength outcomes.(68,69) Consequently, selecting the appropriate conditioner and application protocol should be tailored to the clinical situation and the desired level of adhesion.(70) In a study by Suresh *et al.,*(71) the effects of 10% polyacrylic acid and 37% phosphoric acid on permanent teeth were evaluated prior to the placement of a high-viscosity glass ionomer. The findings demonstrated that 37% phosphoric acid improved the penetration depth of the material into dentin, suggesting its potential advantage as a surface conditioner.

Equia Forte has shown favorable marginal integrity and minimal microleakage compared with conventional GICs and RMGICs. Singh *et al.,*[72] and Ali *et al.,*[73] confirmed Equia Forte's superiority over Fuji II LC and other conventional glass ionomers in reducing microleakage at the occlusal and cervical levels. A recent systematic review confirmed the suitability of Equia Forte for clinical scenarios requiring durable and reliable adhesion, particularly in cases susceptible to marginal leakage.[74]

GH-GICs reliably bond to tooth structures through chemical adhesion and micromechanical interlocking, demonstrating favorable marginal integrity and minimal microleakage. However, their bond strengths typically remain lower than those of resin composites combined with universal adhesives. This limitation should be considered during clinical decision-making, particularly in demanding adhesive scenarios.

Bonding to the resin composite

The utilization of universal bonding agents shows promise in improving the bond strength between resin composites and GH-GICs in layered restorations. Farshidfar *et al.,*[22] investigated the impact of two universal bonding agents (Clearfil Universal Bond and G-Premio Bond) on the microtensile bond strength (µTBS) of Equia Forte Fil, Riva SC, Fuji II LC, and Riva Light Cure combined with a resin composite (Kalore, GC) with or without 35% phosphoric acid. Both adhesive agents significantly enhanced the µTBS across all the materials, with RMGICs such as Fuji II LC and Riva Light Cure exhibiting higher µTBS values than Equia Forte Fil and Riva SC. Furthermore, the application of universal adhesive agents (in the etch and rinse mode) notably improved the µTBS of both conventional GICs and RMGICs to the resin composite compared with that without acid etching. In another study, Francois *et al.,*[75] explored the SBS and interface characteristics between a resin composite (Filtek Z350) and various materials, including Equia Forte Fil, Fuji IX, Fuji II LC, a bulk-fill flowable resin composite (SDR), and a regular flowable resin composite (Tetric Evo Flow), via different adhesive systems. The study concluded that the most effective bonding between the resin composite and HV-GICs was achieved via a universal adhesive in self-etch mode. Additionally, they observed intimate contact at all the interfaces examined, noting that the SBS to Equia Forte Fil varied significantly depending on the adhesive system used, with Scotchbond Universal in self-etch mode showing the highest SBS compared with the other systems.[75] Moreover, beyond enhancing interfacial adhesion, adhesives have also been reported to reinforce the underlying glass-hybrid substrate. Alqasabi *et al.,*[76] reported that these adhesive agents create a superficial laminate that increases surface hardness and reduces moisture-related degradation of GH-GICs.

However, although universal adhesives significantly enhance bonding between GH-GICs and resin composites, especially in self-etch or selective-etch modes, the bond strengths typically remain inferior to those of composite-to-composite bonding. This reflects the inherent limitations and complexity associated with layered restorations involving GH-GICs and resin composites, necessitating careful clinical consideration. Additionally, evidence regarding long-term aging effects on GH-GIC-to-composite bonding is limited, indicating the need for further investigations into durability and bond stability over time. Similarly, the potential influence of the GH-GIC layer thickness on the bond strength remains unclear and warrants future research to guide clinical protocols more effectively.

The clinical performance of GH-GICs

Several clinical studies have explored the efficacy of glass hybrid restorative systems in various clinical scenarios, including class I[25,28,30] and class II cavities.[29,77-79] A summary of these studies is presented in Table 3. GH-GICs have been established as viable choices for class I restorations[25,28,30] and small to large two-surface class II restorations.[77-79] El-Bialy *et al.,*[28] reported comparable clinical outcomes between Equia Forte Fil and Equia Fil in occlusal cavities among high-caries-risk patients after one year. Similarly, Uyumaz *et al.,*[25] demonstrated equivalent and successful clinical outcomes of Equia Forte HT coated with Equia Forte Coat compared with resin composites after one year. A long-term study comparing Equia Forte with a microfilled resin composite (Gradia Direct Posterior, GC) in class I and class II cavities over 10 years revealed comparable durability, clinical effectiveness, and maintenance of surface textures.[7]

Gurgan *et al.,*[77] evaluated Equia Forte against a microhybrid resin composite (G-ænial Posterior) in large, deep class II restorations. Despite the significant color discrepancy with glass hybrid restorations, Equia Forte exhibited a relatively high success rate after 2 years in extended class II cavities, similar to the tested resin composite. The glass hybrid restorative system showed no significant disparities in terms of retention, anatomical form, or proximal contact points. Wafaie *et al.*,[78] found that HV-GICs, including Equia Forte, performed adequately in small-to-medium class II cavities over five years but exhibited surface luster deterioration and color mismatch. Similarly, Miletic *et al.*,[79] observed comparable success between Equia Forte and a nanohybrid resin composite (Tetric EvoCeram) in moderate-to-large two-surface class II cavities at five years. However, Balkaya *et al.*,[29,80] reported superior clinical performance of resin composites over GH-GICs after one and two years, suggesting that caution should be taken in the use of GH-GICs for larger restorations. Gurses *et al.*,[81] Furthermore, HV-GICs exhibited lower clinical effectiveness than did bulk-fill resin composites in class II restorations.

Clinical evidence generally supports GH-GICs as promising alternatives under specific conditions. Indication criteria for selecting GH-GICs should consider caries risk, as these materials provide fluoride release and remineralization, making them suitable for high-caries-risk patients. The size and location of the cavity are also critical, with GH-GICs recommended primarily for class I cavities and small-to-medium-sized class II cavities where functional and esthetic demands are moderate. Additionally, these materials offer clinical convenience and are particularly beneficial in scenarios requiring rapid, straightforward placement, such as pediatric, geriatric, or medically compromised patients. Conversely, their reduced translucency and potential color mismatch limit their suitability for anterior restorations or highly visible posterior restorations. The observed performance deterioration in larger restorations and increased aesthetic demands highlight the need for clinicians to carefully balance these factors when choosing GH-GIC restorations. Further standardized long-term clinical trials are essential to clarify and refine these indications, guiding clinicians toward optimal clinical outcomes. Recognizing discrepancies in study designs, methodologies, and evaluation criteria among available studies emphasizes the need for standardized approaches to establish universally applicable clinical guidelines for GH-GIC use. A summary of the

Table 3: Summary of clinical and *in vitro* studies comparing glass HV-GICs and GH-GICs and other restorative materials.

A. Clinical studies investigating the performance and outcomes of HV-GICs and GH-GICs in class I and II restorations				
Study	**Year**	**Materials**	**Classes**	**Outcomes/Results**
Klinke *et al.*,[30]	2016	Equia system vs. Fuji IX GP Fast + Fuji Coat LC	Small to moderate class I and II	Comparable performance in class I; Equia system superior in class II restorations with fewer failures.
Türkün & Kanik[33]	2016	Equia system vs. Riva SC + Fuji Varnish	Moderate to large class I and II	Equia Fil showed better performance in class I and II restorations over 6 years; coatings wore off after 6 months.
Kharma *et al.*,[26]	2018	Equia system vs. microhybrid resin composite (Amelogen Plus)	Small class I	No statistical significance difference between both in anatomical shape, color, postoperative sensitivity, secondary caries, material handling, adaptation, and marginal staining after 9 months. Equia surface texture decreased overtime.
Balkaya *et al.*,[29]	2019	Equia Forte system, bulk-fill resin composite (Equia Forte system), microhybrid resin composite (Charisma Smart).	Small to moderate class I and II	Resin composites showed better clinical performance than Equia Forte system after 1 and 2 years.
Heck *et al.*,[32]	2020	Fuji IX GP Fast + Fuji Coat LC vs. Equia system	Small class II	Both materials showed acceptable survival rates; significant deterioration in surface luster, marginal adaptation, and retention over 6 years.

Gurgan *et al.*,[77]	2020	Equia Forte system vs. microhybrid resin composite (G-ænial Posterior)	Large class II	Equia Forte showed significant mismatch in color, both materials exhibited successful performance for the restoration of large class II cavities after 24 months.
El-Bialy *et al.*,[28]	2020	Equia Forte Fil vs. Equia Fil	Small class I	Comparable performance after 1 year in high-caries-risk patients.
Hatirli *et al.*,[24]	2021	Equia system vs. nanohybrid resin composite (GrandioSO)	Small class I	Equia system showed comparable performance to resin composite; lower marginal discolouration but greater surface wear.
Rożniatowski *et al.*,[31]	2021	Equia system vs. resin composite (Tetric EvoCeram)	Class II	Similar efficacy over 2 years; Equia had higher risk of marginal adaptation deterioration, staining and erosion.
Uzel *et al.*,[27]	2022	Equia system vs. bulk-fill resin composite (Tetric EvoCeram)	Small to moderate class I and II	Both materials showed good clinical performance; Equia had more chipping and surface degradation over 2 years.
Wafaie *et al.*,[78]	2022	Ketac Universal Aplicap, Equia Forte and Riva Self Cure HV vs. microhybrid resin composite (Filtek Z250)	Small to moderate class I and II	Although drawbacks in surface luster and color match appeared over the 5-year period, the three high-viscosity glass ionomers had successful clinical performance compared to Filtek Z250
Uyumaz *et al.*,[82]	2023	Equia Forte HT system vs. microhybrid resin composite (Charisma Smart)	Small class I	Resin composite outperform Equia Forte HT system in terms of color match and surface texture. Comparable clinical performance after 1 year.
Gurses *et al.*,[81]	2023	Two Bulk-fill Resin composites (Tetric EvoCeram Bulk-Fill and Filtek Bulk-Fill) vs. Equia Forte system.	Small to moderate class I and II	Both bulk-fill resin composites had comparable clinical performance; Equia Forte system showed lower clinical effectiveness after 2 years.
Miletić *et al.*,[79]	2024	Equia Forte system vs. nanohybrid resin composite (Tetric EvoCeram)	Small to moderate class I and II	Both materials showed satisfactory survival and success rates over 5 years.
B. *In vitro* studies investigating mechanical and physical properties of GH-GICs				
Kutuk *et al.*,[46]	2019	Equia Forte system vs. microhybrid resin composite (G-ænial Posterior)	No significant difference in fracture resistance; resin composite had higher compressive strength.	
Šalinović *et al.*,[40]	2019	Equia Forte Fil vs. Ketac Universal Aplicap vs. Equia Fil	No significant difference in compressive strength; Ketac Universal Aplicap had higher hardness values than Equia fil and Equia Forte fil.	
Moshaverinia *et al.*,[34]	2019	ChemFil Rock vs. Fuji IX GP vs. Equia Forte Fil	Equia Forte Fil had higher flexural strength and surface hardness than Fuji IX GP, with no significant difference in compressive or diametral tensile strength. Equia Forte released significantly more fluoride after 4 weeks compared to Fuji IX GP and ChemFil Rock. ChemFil Rock showed higher flexural strength (not statistically significant) but lower compressive strength and microhardness than Equia Forte Fil.	
Fuhrmann *et al.*,[37]	2020	Equia Forte vs. Ketac Universal Aplicap vs. ChemFil Rock vs. Fuji IX Extra vs. IonoStar Molar vs. resin composites (Filtek Z250 and Filtek Supreme Ultra)	The resin composite restorative materials had significantly greater fracture toughness than the glass-ionomer materials. There was no significant difference in fracture toughness between the glass-ionomer materials. Equia Forte Coat improved surface hardness but did not affect fracture toughness.	

Yeo *et al.,*[38]	2021	Filtek Z350 vs. Filtek One Bulk Fill vs. Fuji IX vs. Equia Forte	Resin composites had higher flexural strength and translucency than Equia Forte and Fuji IX. Fuji IX and Equia Forte had similar flexural strength. Coating did not enhance elastic modulus and may increase wear.
Habib *et al.,*[51]	2021	Equia Forte Fil vs. RMGIC (Fuji II LC) with and without coatings	Coating improved flexural strength, reduced surface roughness, and decreased microleakage.
Kunte *et al.,*[35]	2022	Fuji IX vs. Equia Forte Fil	Equia Forte showed slightly higher compressive and diametral tensile strength, but differences were not statistically significant.
Valeri *et al.,*[47]	2022	RMGIC (Ionolux) vs. Activa Bioactuce Restorative vs. Equia Forte HT system vs. resin composite (Filtek Supreme Ultra)	Ionolux and Activa Bioactive Restorative had comparable or less wear compared to Filtek Supreme Ultra, while Equia Forte HT wore twice as much compared to the resin composite.
Moshaverinia *et al.,*[39]	2024	Equia Forte HT vs. Fuji IX GP vs. ChemFil Rock	Equia Forte HT had improved translucency, compressive strength, flexural strength and fluoride release compared to Fuji IX. No significant difference was found in flexural strength values between Equia Forte HT and Chemfil Rock.
Abuzinadeh *et al.,*[83]	2024	Fuji IX, vs. Equia Forte vs. Fuji II vs. resin composite (Tetric-N-Ceram Bulk Fill)	Equia Forte had comparable compressive strength and microhardness to Fuji II and Fuji IX. The resin composite had the highest compressive strength and microhardness among all materials. The study results showed statistically insignificant differences in surface microhardness across all groups. Equia Forte was 40% lower microhardness values than the other materials.

included studies is presented in Table 3.

This review highlights several limitations within the literature on GH-GICs. First, there is significant variability in study designs, methodologies, evaluation criteria, and follow-up periods among clinical studies, complicating direct comparisons and generalized conclusions regarding long-term efficacy. Many existing studies have short-term follow-up periods (≤ 5 years), limiting the understanding of long-term clinical outcomes, especially concerning durability and aesthetic stability.

Additionally, the performance of the resin coatings used with GH-GICs has been inconsistently reported, with varying results in terms of long-term mechanical properties and fluoride release. This inconsistency suggests that resin coating formulations and application protocols require further refinement and standardized testing to clearly determine their long-term effectiveness.

Future research should focus on conducting long-term randomized controlled clinical trials with standardized methodologies to provide robust data on the longevity and clinical performance of GH-GIC restorations, particularly moderate-to-large posterior restorations. Studies examining long-term biological impacts, such as fluoride release and remineralization capacity in clinically relevant scenarios, are also needed. Furthermore, investigations into optimizing resin coatings, exploring new formulations, and assessing their effects on mechanical and biological properties will enhance the clinical applicability and reliability of GH-GICs. Such research directions will significantly inform clinical decision-making and expand the potential applications of these promising restorative materials.

Conclusions

GH-GICs represent a notable advancement in restorative dentistry, successfully addressing several limitations of conventional glass ionomer cements through improved mechanical performance, fluoride release, and ease of clinical application. Clinically, GH-GICs demonstrate comparable effectiveness to resin composites in class I and small to moderate class II posterior restorations. Despite these advancements, challenges remain, particularly in larger restorations, including marginal deterioration, surface wear, and limited aesthetic outcomes. While resin coatings enhance initial mechanical durability, their short-lived effectiveness and reduced fluoride release may limit long-term benefits. GH-GICs, therefore, are particularly recommended for specific patient groups, such as those with high caries risk and pediatric, geriatric, and medically compromised populations, where their biological advantages outweigh their aesthetic and mechanical limitations. Future research should prioritize long-term clinical evaluations and innovative enhancements in resin coatings to further expand the clinical applicability and durability of GH-GICs.

Conflicts of Interest

The author declare that they have no conflicts of interest.

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Regression Equations for Prediction of Permanent Canine and Premolar Mesiodistal Width in Thai Population: A Cross-sectional Study

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Abstract

Objectives: This study aimed to formulate regression equation(s) for predicting human permanent canine and premolar mesiodistal (MD) widths of Thai population.

Methods: 176 Mae Fah Luang University students with Thai nationality were selected for this study. Based on their domicile, participants were grouped by four different regions of Thailand, including central, northern, southern, and northeastern. An intraoral scanner was used to record digital dental models, and the tooth MD widths were measured using SolidWorks 2020 EP1 software. Significant differences were tested by two-sample *t*-test or one-way ANOVA. By Pearson's correlation coefficient, the relationships between the maxillary and/or mandibular incisor MD width and the upper and/or lower canine and premolar MD widths were determined for prediction equations.

Results: There were statistically significant differences in a sum of the maxillary and mandibular incisor and in that of the upper and lower canine and premolar MD widths between males and females (p<0.001). Statistically significant differences in the sum of the mandibular incisor MD width and in that of the maxillary and mandibular central incisor MD width were found among four different regions (p<0.05). By linear regression analysis, correlation coefficients of eight prediction equations were between 0.62 and 0.75 with the percentages of prediction accuracy from 47.16 to 53.41. These percentages were significantly greater than those predicted by previous models for the upper canine and premolar MD widths (p<0.01).

Conclusions: Our novel regression equations may predict the MD width of unerupted canine and premolars of Thai population precisely enough to be applicable for mixed dentition space analysis.

Keywords: canine, intraoral scanner, mixed dentition, premolar, regression equation, tooth size prediction

Introduction

Analysis of a mixed dentition space is a crucial step in orthodontic treatment planning. Thus, determination of mesiodistal (MD) width of unerupted canine and premolars from that of fully erupted maxillary and/or mandibular incisors is beneficial for treatment planning of orthodontists in order to select a proper treatment of choice.(1) Prediction of the MD width of the unerupted canine and premolars can be carried out by three ways: 1) a direct measurement of the unerupted teeth from dental radiographs(2), 2) an estimation from proportionality tables or prediction equations(3,4), and 3) a combination of the two methods, as aforementioned.(5) The Moyers' probability tables(3) and the Tanaka and Johnston prediction equations(4) gain popularity due to no need for dental radiography. However, both tables and equations are derived from data of Northern European populations, limiting their use in other countries. Thus, their orthodontic applications in other ethnic groups should be proceeded with caution because tooth sizes vary owing to differences from several intrinsic and extrinsic factors, such as, ethnicity, genetic, sex, and nutrition.(6) The distinction in tooth sizes among different ethnic groups of Asian populations was demonstrated in five previous studies, including 1) a study in Hong Kong Chinese;(7) 2) that in northeastern Thai population;(8) 3) that in northeastern Han Chinese;(9) 4) that in Nepalese mongoloids;(10) and 5) that in Pakistani population.(11) However, the equations obtained from these studies do not precisely predict the real MD width of canine and premolars; therefore, their clinical implications in orthodontic treatment planning are questionable.

Among the five studies, a plaster model was used to measure the tooth size. Nowadays, use of an intraoral scanner (IOS) has, however, increasingly gained popularity because it offers greater reliability and accuracy than the traditional impression.(12) Consequently, tooth size measurement from a digital dental model can yield an accuracy sufficiently to determine the MD width of permanent canine and premolars.(13) This study aimed to formulate new prediction equations for the MD width of permanent canine and premolars in a Thai population, based on the MD widths of their maxillary and/or mandibular incisors, measured from the digital dental models. Furthermore, this study was conducted in four different regions of Thailand to represent data of general Thais.

Material and Methods

Eligible participants were 14,432 university students of Mae Fah Luang University (MFU) in 2023 with Thai nationality. Of these students, a total of 238, whose domicile was from each of the four regions of Thailand, including central (n=62), northern (n=64), northeastern (n=48), or southern (n=64), were interested to enroll into this study (Figure 1). According to the sample size calculation, determined by the finite population mean formula with standard deviation at 1.36, standard error at 0.20,(8) and an alpha value at 0.05, a cohort of 176 students was required to have enough power of test. The mean age of 176 participants was 20.93 years. There were an equal number of 44 selected participants (male=22, female=22) within each region (Figure 1). The selection of 22 male and 22 female participants within each region was based on their first arrival for oral examination after enrollment with the selection criteria as follows: i) participants with all fully erupted permanent teeth, except their third molars, ii) those without tooth malformations, missing, or severe tooth crowding, iii) those without proximal caries or restorations, and iv) those without previous orthodontic treatment. An ethical approval was granted by the Human Ethics Committee of MFU, Thailand (EC 23186-22), and written informed consent was obtained. The IOS (Primscan, Dentsply Sirona, Bensheim, Germany) was used to create digital dental models.

Before actual measurements, five examiners were standardized to yield intra- and inter-examiner reliabilities, as assessed by Cohen's Kappa and Dahlberg's error, respectively. The inter-examiner standardization of MD width measurement was performed by comparisons with an experienced examiner. To test the intra-examiner reliability, the same digital dental model was randomly selected and measured twice within one week by the same examiner. The inter and intraclass correlation coefficients were 0.95 and 0.92-0.98, respectively.

Measurement of MD width

The Standard Tessellation Language files derived from the IOS were measured using SolidWorks 2020 EP1 software (Dassault Systèmes SolidWorks Corp., Bensheim, Germany). The MD width of each tooth was first determined from the mesial to the distal point of anatomical contact with the adjacent tooth, viewed at the labial or the buccal surface (Figure 2A or B). Then, the first MD width was confirmed by the greatest proximal contour of

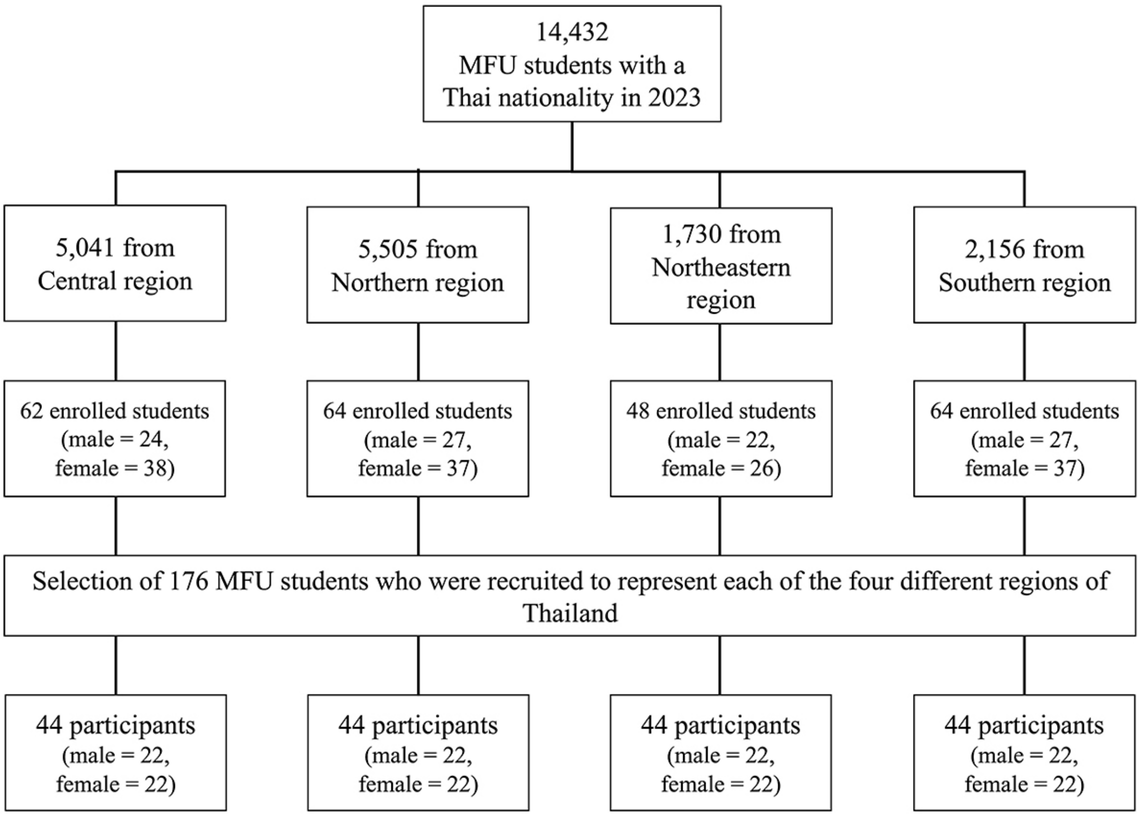

Figure 1: A flow chart of selected 176 university students of Mae Fah Luang University (MFU), recruited to represent each of the four regions of Thailand.

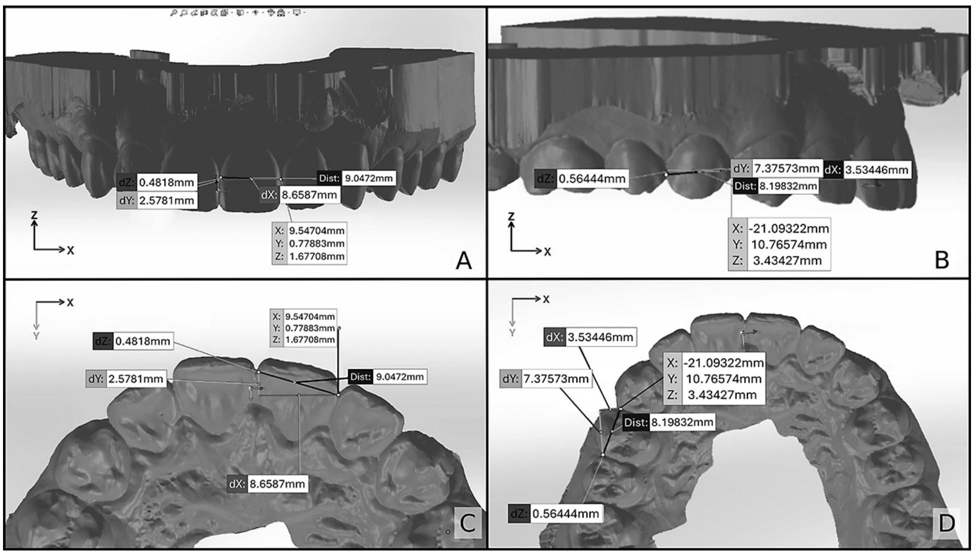

Figure 2: Representative images of a digital dental model, used in the measurement of mesiodistal width of permanent left central incisor, viewed at the labial surface (A) and the incisal edge (C). Those used in the measurement of mesiodistal width of permanent right first premolar, viewed at the buccal surface (B) and the occlusal plane (D). Numbers in the boxes indicate values on x, y, and z axes, the distance of mesiodistal width (Dist=distance), dX, dY, and dZ (Δ distance of x, y, z axes).

that tooth, viewed at the incisal edge or the occlusal plane (Figure 2C or D).

Statistical analysis

The datasets were analyzed using STATA software version 16.1 (StataCorp, TX, USA) with the confidence level at 5%. Categorical variables were described by frequencies and percentages. Based on normal distribution, continuous variables were presented with mean and standard deviation. Comparisons of MD width between sexes and among regions were analyzed by Student's *t*-test and one-way ANOVA, respectively.

Two pre-reducing models were created by generalized linear regression for sums of upper/lower canine and premolars using four predictors, including a sum of mandibular incisors, that of maxillary central incisors, that of mandibular central incisors, and that of maxillary and mandibular central incisors. The post-reducing models were created by a stepwise backward elimination method upon removal of variables (sexes, regions, or four predictors) if $p>0.05$.

The acceptable prediction accuracy of two outcomes was within ±0.5 mm. The relationships between prediction accuracy of our equations, the Moyers' probability tables, or the Tanaka and Johnston prediction equations, and an exact width of the sum of upper/lower canine and premolars, measured form digital models, were analyzed by Pearson's correlation.

Results

Comparisons of MD widths between males and females or among four regions

Male participants had significantly greater mean MD widths than females in all four predictors and two outcomes ($p<0.001$; Table 1). Of the four predictors, significant differences were found in the three predictors ($p<0.05$; Table 2). Note that the greatest mean MD widths of three predictors were found in participants from the southern region (Table 2). However, no significant differences in the mean MD width of the two outcomes were found among four different regions (Table 2).

Correlations between predictors and outcomes used to generate regression equations

Since different sexes had a significant impact on prediction of the MD widths of upper/lower canine and premolars ($p<0.001$; Tables 3 and 4, respectively), whereas distinct regions had no significant effect ($p>0.05$), the constants and coefficients of eight formulated equations were adjusted in the post-reducing model, based on the sex parameter.

The first four (Table 3) and the second four equations (Table 4) were used to predict a sum of the MD width of canine (3), first premolar (4), and second premolar (5). U=upper; L=lower; XX=female; XY=male.

1. U345=13.41-0.48(XX=1 or XY=0) + 0.44(sum of 42, 41, 31, 32)
2. U345=14.40-0.52(XX=1 or XY=0) + 0.54(sum of 11, 21)
3. U345=14.58-0.49(XX=1 or XY=0) + 0.81(sum of 41, 31)
4. U345=12.30-0.44(XX=1 or XY=0) + 0.40(sum of 41, 31, 11, 21)
5. L345=10.76-0.47(XX=1 or XY=0) + 0.51(sum of 42, 41, 31, 32)
6. L345=11.81-0.52(XX=1 or XY=0) + 0.63(sum of 11, 21)
7. L345=12.12-0.49(XX=1 or XY=0) + 0.94(sum of 41, 31)
8. L345=9.40-0.43(XX=1 or XY=0) + 0.47(sum of 41, 31, 11, 21)

Comparisons of the eight prediction equations with Moyers' probability tables and Tanaka and Johnston prediction equations

The correlation coefficients for eight prediction equations were found to be moderate to strong, or from 0.62 to 0.75 (Table 5). The percentages of prediction accuracy of the eight prediction equations, ranging from 47.16 to 53.41 (Table 5), were compared with those using the Moyers' tables and the Tanaka and Johnston equations. For the first four equations, the percentages of prediction accuracy were significantly greater than that using the Moyers' tables ($p<0.001$) and that using the Tanaka and Johnston equations ($p<0.01$; Table 5). For the second four equations, the percentages of prediction accuracy were significantly greater than that using the Moyers' tables ($p<0.05$; Table 5).

Discussion

To predict the MD widths of upper/lower canine and premolars from various combinations of the sum of the

Table 1: Comparisons of the mean mesiodistal (MD) widths of four predictors and two outcomes between Thai male and female participants. U= upper, L= lower.

	MD width	Male Mean±SD (mm)	Female Mean±SD (mm)	*p*-value
Predictors	sum of 42, 41, 31, 32	23.83±1.46	23.08±1.21	<0.001
	sum of 11, 21	17.54±1.14	17.01±0.83	<0.001
	sum of 31, 41	11.39±0.74	11.01±0.63	<0.001
	sum of 11, 21, 31, 41	28.94±1.70	28.02±1.32	<0.001
Outcomes	U345	23.82±1.08	23.02±0.91	<0.001
	L345	22.86±1.09	22.01±0.93	<0.001

Table 2: Comparisons of the mean mesiodistal (MD) widths of four predictors and two outcomes among four different regions of Thailand. U= upper, L= lower.

	MD width	Northern Mean±SD (mm)	Central Mean±SD (mm)	Northeastern Mean±SD (mm)	Southern Mean±SD (mm)	*p*-value
Predictors	sum of 42, 41, 31, 32	23.29±1.51	23.19±1.34	23.29±1.19	24.00±1.36	0.020*
	sum of 11, 21	17.05±1.17	17.24±1.02	17.24±0.95	17.52±0.93	0.185
	sum of 31, 41	11.06±0.72	11.02±0.71	11.18±0.59	11.52±0.71	0.004**
	sum of 11, 21, 31, 41	28.12±1.74	28.26±1.55	28.43±1.38	29.04±1.57	0.029*
Outcomes	U345	23.23±1.07	23.36±0.94	23.42±0.91	23.59±1.31	0.441
	L345	22.28±1.27	22.36±0.98	22.41±1.05	22.62±1.07	0.513

*$p<0.05$; **$p<0.01$

Table 3: Regression parameters for the correlation of predictor and outcome variables of upper canine and premolars (upper 3 4 5) upon pre- and post-reducing models.

	Upper 3 4 5				
	Pre-reducing model		Post-reducing model		
	Coefficient	*p*-value	Coefficient	*p*-value	Power
Sex	-0.490	<0.001	-0.480	<0.001	1
Region	0.030	0.570	-	-	-
sum of 42, 41, 31, 32	0.430	<0.001	0.440	<0.001	1
Constant	13.490	<0.001	13.410	<0.001	-
Sex	-0.530	<0.001	-0.520	<0.001	1
Region	-0.050	0.355	-	-	-
sum of 11, 21	0.530	<0.001	0.540	<0.001	1
Constant	14.510	<0.001	14.400	<0.001	-
Sex	-0.500	<0.001	-0.490	<0.001	1
Region	0.005	0.935	-	-	-
sum of 31, 41	0.810	<0.001	0.810	<0.001	1
Constant	14.600	<0.001	14.580	<0.001	-
Sex	-0.440	0.001	-0.440	0.001	1
Region	0.010	0.863	-	-	-
sum of 11, 21, 31, 41	0.400	<0.001	0.400	<0.001	1
Constant	12.330	<0.001	12.300	<0.001	-

Table 4: Regression parameters (sex and region) for the correlation of predictor and outcome variables of lower canine and premolars (lower 3 4 5) upon pre- and post-reducing models.

	Lower 3 4 5				
	Pre-reducing model		Post-reducing model		
	Coefficient	*p*-value	Coefficient	*p*-value	Power
Sex	-0.470	<0.001	-0.470	<0.001	1
Region	0.005	0.924	-	-	-
sum of 42, 41, 31, 32	0.510	<0.001	0.510	<0.001	1
Constant	10.770	<0.001	10.760	<0.001	-
Sex	-0.530	<0.001	-0.520	<0.001	1
Region	0.030	0.588	-	-	-
sum of 11, 21	0.620	<0.001	0.630	<0.001	1
Constant	11.880	<0.001	11.810	<0.001	-
Sex	-0.490	<0.001	-0.490	<0.001	1
Region	0.030	0.619	-	-	-
sum of 31, 41	0.950	<0.001	0.940	<0.001	1
Constant	12.030	<0.001	12.120	<0.001	-
Sex	-0.420	<0.001	-0.430	<0.001	1
Region	0.020	0.665	-	-	-
sum of 11, 21, 31, 41	0.470	<0.001	0.470	<0.001	1
Constant	9.320	<0.001	9.400	<0.001	-

Table 5: Comparisons of eight prediction equations with Moyer's proportionality tables and Tanaka and Johnston prediction equations. U= upper, L= lower.

		% accuracy in this study	Correlation coefficient (r)	% accuracy using Moyers	Correlation coefficient (r)	Chi-Square *p*-value (1)	% accuracy using Tanaka and Johnston	Correlation coefficient (r)	Chi-Square *p*-value (2)
U345	sum of 42, 41, 31, 32	48.30	0.66	10.91	0.55	<0.001	31.25	0.63	0.001
	sum of 11, 21	48.30	0.62			<0.001			0.001
	sum of 31, 41	47.73	0.64			<0.001			0.002
	sum of 11, 21, 31, 41	47.16	0.68			<0.001			0.002
L345	sum of 42, 41, 31, 32	53.41	0.73	38.79	0.69	0.007	51.14	0.70	0.670
	sum of 11, 21	48.30	0.69			0.017			0.920
	sum of 31, 41	51.14	0.70			0.022			1.000
	sum of 11, 21, 31, 41	51.14	0.75			0.022			1.000

p-values (1) or (2), comparisons between % accuracy in this study and that by Moyers' tables or that by Tanaka and Johnston equations, respectively.

MD widths of incisors, this study has proposed eight novel prediction equations, whose percentages were found to be significantly greater than those using Moyers' tables. The correlation coefficients for the upper canine and premolars from 0.62 to 0.68 were greater than that at 0.55 using the Moyers' tables, while those for the lower canine and premolars from 0.69 to 0.75 were comparable to that using the Moyers' tables or the Tanaka and Johnston equations. Collectively, these percentages and coefficients suggest the accuracy and reliability of our eight prediction equations be acceptable for prediction of the upper/lower permanent canine and premolar MD width of Thai population.

The Moyers' tables were developed from Northern European populations that are neither accurate nor applicable for other populations of distinct ethnic origins. The ideal correlation coefficient at 0.75, as recommended by the author,(3) is not observed in seven of the eight equations in this study (Table 5), nor is it found in another study.(14) When the Moyers' tables were applied for the Thai population in this study and in the Chinese population(7,9,15), it was found to underestimate the real MD width of upper canine and premolars that would affect orthodontic treatment planning, because more space than the predicted MD width is required for a good alignment of the erupting canine and premolars. In comparison with the Tanaka and Johnston equations, our equations were found to significantly better predict a sum of the MD width of upper canine and premolars. Note that the Tanaka and Johnston equations overestimate the mixed dentition space analysis of female Caucasians, while they underestimate the same analysis of male and female Negroids.(16) In this study, the Tanaka and Johnston equations also underestimate the mixed dentition space analysis of upper canine and premolars of Thai males and females (data not shown).

Of the eight equations, only six that did not include maxillary and mandibular lateral incisors are clinically applied in patients, whose lateral incisors are frequently afflicted by congenital missing and/or abnormal tooth size. A recent article(17) has reviewed using different predictors other than the incisors, particularly the MD width of permanent first molar. These predictors include a sum of the MD width of mandibular central incisor, lateral incisor, and first molar, and that of two mandibular central incisors and first molar. Hence, various combinations of predictors, considered to be advantageous in terms of a more diverse manner, are created. Note that the correlation coefficients of our eight prediction equations are found to be comparable to those using the combinations of the MD width of incisors and molars.(17) Nonetheless, tooth defects from dental caries or restoration involving the MD surface of permanent first molar often take place, affecting its real MD width, necessitating use of anterior teeth instead to predict the MD width of unerupted canine and premolars. In this study, sex evidently affects tooth size, by which the average size of each tooth type of males was found to be significantly larger than that of females. This finding is consistent with the previous findings in the Thai population.(8) Correspondingly, a study in the Taiwanese population(15) has shown a similar result that indicates a significantly larger tooth size in men than in women. The sex effect on tooth size could be attributed to genetic factors and sex hormones that influence tooth development.(6,18,19) Each of the four regions in Thailand differs in terms of geography, ethnicity, cultural heritage, and cuisine. Our findings indicated that regional differences had a significant effect on three of the four predictors with the greatest mean MD widths found in participants from the southern region of Thailand. These results agree with the findings from a previous study,(8) which suggest that regional differences influence tooth size. Nevertheless, regional variables, which were not found to have any significant impact in a pre-reducing model (Tables 3 and 4), were not included in the formulation of our equations in a post-reducing model, thus, making these equations simpler and more generalizable for use in the Thai population. Because of its convenience, intraoral scanning has increasingly gained popularity in orthodontic treatment nowadays.(11-13) The digitized dental images can be indirectly obtained from scanning the plaster models(11), whereas our digital dental models were derived directly from intraoral scanning. A previous study(20) has shown no significant difference between these two approaches, since an excellent agreement in the measurement of MD width obtained from either direct or indirect way was demonstrated. Thus, due to its ease, convenience, time saving, cost effective, reliability, and accuracy, intraoral scanning is recommended to directly create digital dental models. However, it is noteworthy that the measurement of MD width in this study was performed by only a specific brand of intraoral scanner; therefore, differences in the scanner accuracy, resolution, and software algorithms between the different scanners may have influenced the validity and generalizability of our findings.

Conclusions

In the Thai population, significantly larger tooth sizes in males than in females affect the prediction of upper and lower canine and premolar MD widths.

The eight MFU regression equations are precise to predict the sum of the MD width of upper/lower canine and premolars, proposing a possibility to use these equations to predict the MD width of unerupted permanent canine and premolars for orthodontic treatment planning during the mixed dentition.

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Apical Debris Extrusion of Rotary and Reciprocating Files Combined with Two Supplementary Irrigation Techniques

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Abstract

Objectives: To quantify the amount of debris extrusion after root canal instrumentation with rotary (Zenflex; ZF) and reciprocating (EdgeOne Fire; EOF) file systems combined with either Manual Dynamic Activation (MDA) or Passive Ultrasonic Irrigation (PUI).

Methods: Ninety mandibular molars with complete root formation and 10°-20° curvature were selected, disinfected, and stored. Teeth with immature apex, resorption, caries, or calcified canals were excluded. High-speed diamond burs accessed the teeth and mesial roots were used for investigation. Specimen were randomly divided into 6 groups (n=15) based on file (ZF and EOF) and irrigation systems(MDA and PUI). The apical size of prepared root canal was 25. The Myers and Montgomery method was used to collect apical debris. Debris extrusion was measured by weighing tubes pre- and post-experiment after incubating for 5 days. The mean weight differences of debris extrusion among file and irrigation system groups were compared using Two-way ANOVA with Tukey's test.

Results: The statistics showed a significant effect of irrigation technique on debris extrusion (p=0.002), while file system (p=0.698) and interaction (p=0.406) were not significant. PUI as an adjunctive irrigation with ZF and EOF (mean=0.19±0.17 and 0.19±0.14 µg respectively) significantly reduced debris extrusion compared to reciprocating EOF systems without adjunctive irrigation technique (mean=0.37±0.13 µg) (p=0.020 and p=0.017, respectively).

Conclusions: Irrigation technique significantly influenced debris extrusion, while file system had no effect. The use of PUI with both file systems reduced debris extrusion compared to EOF without adjunctive irrigation.

Keywords: apical debris extrusion, mechanical instrumentation, root canal preparation, rotary NiTi file

Introduction

Complete root canal debridement, achieved through chemical irrigants and mechanical instrumentation, is a critical step in non-surgical root canal treatment.[1,2] Chemomechanical debridement can lead to apical extrusion of debris, pulp tissue fragments, necrotic tissue, microorganism and irrigants which is one of the main causes of periapical inflammation and postoperative flare-ups.[3] Flare-ups, characterized by pain, swelling, or both, may occur within hours or days following root canal treatment and often result in unexpected interappointment emergency visits. The incidence of flare-ups during root canal treatment ranges from 1.4% to 16%.[1-3]

Despite efforts to maintain the working length short of the apical terminus across various preparation techniques and instruments, debris extrusion continues to occur in varying amounts.[2,3] Studies showed mechanical instrumentation using hand files produced more apical debris extrusion than engine-driven rotary preparation.[1,3] Moreover, push-pull filing motions generate more apical debris than rotational motions.[2]

Recently, advances in Nickel-Titanium (NiTi) rotary file technology have facilitated more effective cleaning and shaping of the root canal system. These improvements in metallurgy allow for greater preservation of tooth structure while maintaining canal anatomy. However, the literature remains inconclusive regarding the differences in apical debris extrusion between various rotary file systems. Earlier studies indicated that reciprocating file system produces more debris extrusion than continuous rotation file system[2,3], while study of Ujariya *et al.,*[4] reported inconsistent result. Recently, Kerr Corporation launched a new NiTi rotary system used in continuous motion called ZenFlex™ (Kerr Corporation, Pomona, CA, USA) which characterized by 1 mm maximum instrument diameter with the purpose to maintain more tooth structure after root canal preparation. Moreover, the manufacturer claimed of ensuring an increased cyclic fatigue and torsional resistance in comparison to other comparable instrument brands due to the proper heat treatment and the innovative design of ZenFlex™.[5]

EdgeOne Fire™ (EdgeEndo, Albuquerque, NM, USA), a recently introduced reciprocating file system, undergoes proprietary heat treatment (FireWire™) to enhance flexibility and a negligible restoring force.[6] A comparative study on the shaping ability of three reciprocating NiTi single file systems; Reciproc® blue, WaveOne® Gold and EdgeOne Fire™, in curved root canals reported that there were no statistically significant differences in the degree of canal transportation distances and preparation times among these 3 groups. The EdgeOne Fire system recorded more statistically significant percent change of canal curvature than the WaveOne® Gold system. Despite this, there are no data in literature regarding apical debris extrusion of those instruments.

The most commonly used method of smear layer removal has been the alternating irrigation with a combination of ethylenediaminetetraacetic acid (EDTA) and sodium hypochlorite (NaOCl). This combination can remove smear layer completely in the coronal and middle thirds but less effective in the apical third owing to the inability of the irrigating solutions to reach the apical third of the root canals.[7,8] For optimal effectiveness, the irrigants must contact the entire root canal surface. However, complex canal anatomy and the vapor lock effect in the apical third hinder conventional syringe irrigation from wetting the entire surface.[9]

Conventional syringe irrigation typically reaches only 1.5-2.0 mm beyond the needle tip, limiting its effectiveness to the coronal and middle thirds.[10] Therefore, intracanal agitation or activation of the irrigants is a necessary adjunction to mechanical instrumentation to remove debris and bacteria from the root canals.[11,12] Several systems for intracanal agitation of the irrigants have been proposed, which might be categorized as manual agitation devices, including the use of hand files, gutta-percha points and canal brushes, and machine-assisted agitation devices, like sonic or ultrasonic devices, rotary brushes and pressure alternation devices. Studies have shown that manual dynamic activation (MDA) using well-fitting gutta-percha master cone with gentle up and down movement in short 2- to 3-mm strokes in an instrumented canal can produce an effective hydrodynamic effect and significantly improve the displacement and exchange of any given reagent. This will result in better contact of the irrigating solution with the root canal walls, and thus enhance debridement.[13]

Studies indicated that irrigation is one of the procedures that can cause extrusion of intracanal debris into periapical[14,15] area and type of irrigation system can affect the frequency and amount of apical debris extrusion.[16] It has been known that passive ultrasonic irrigation (PUI) is more effective than conventional irrigation (CI), using syringe and needle, in eliminating pulp tissue and dentin debris.[16] PUI can remove debris and bacteria adhered on the root surface by action of acoustic streaming which produces shear stresses along the root canal wall.

To date, the effect of PUI on the apical extrusion of debris when used in conjunction with single-file systems has not been studied much. Studies evaluating the effect of MDA and PUI on the apical extrusion of debris are lacking, and therefore, this study aims to quantify the amount of debris extrusion after root canal instrumentation with rotary and reciprocating file systems combined with either MDA or PUI. The null hypothesis (H_0) is that there is no significant difference in the amount of debris extrusion among different combinations of ZF and EOF file systems with either MDA or PUI.

Materials and Methods

This study was approved by the Human Experimentation Committee, Faculty of Dentistry, Chiang Mai University, Thailand (NO.18/2023).

2.1 Sample size

Sample size was calculated by adopting an alpha (α) level of 0.05, beta (β) level of 0.20 i.e., power = 80%, effect size (f) = 0.4. The calculation based on results of Gummadi *et al.,*[16] using G*power version 3.1.9.7 (Heinrich Heine University, Düsseldorf, Germany) revealed the total sample size is 90 samples.

2.2 Sample selection

Ninety mandibular molars (except mandibular third molar) were collected and stored in normal saline. The included teeth had complete root formation with root curvature approximately 10º-20º measured by Schneider method.[17] Calculus and debris were removed with ultrasonic scaling and disinfected with 5.25% NaOCl for 10 minutes then stored in normal saline until used. Periapical radiographs in mesiodistal and buccolingual views had been taken to verify apical foramen and root canal configuration. Only teeth which mesial root had type II or IV Vertucci's configuration were included in this study. Teeth with immature apex, root resorption, root caries, and calcified canal were excluded.

2.3 Experimental model design

The mesiobuccal canal of mesial root was used in our study. Each specimen was created by the following procedure. High-speed diamond burs were used to access the teeth and to separate the distal and mesial roots. In the mesial roots, the canals were checked for apical patency with K-file no.10 (Densply Sirona, Ballaigues, Switzerland). The length of each canal was established by inserting no.10 K-file into canal space until the tip of file was visible at apical foramen, then subtract 1 mm. The final working length of mesiobuccal canal was 16 mm and adjusted by flattening the cusp tip, then confirmed with a radiograph. A K-file no.15 inserted until the working length was reached and teeth which had a passive fit at the working length were selected. Teeth were divided randomly into 6 groups based on the file system and the irrigation system (n=15).

2.4 Specimen preparation and debris collection model

The model and process for collecting apical debris extrusion was adopted from Myers and Montgomery method (Figure 1).[18] Double layer of cyanoacrylate used to cover the external surface of all roots except for 1 mm from root apex. Each empty Eppendorf tubes were numbered and weighed without the lids by 5-digit analytical balance (Shimadzu, Kyoto, Japan). Pre-experimental weight of tube (W1) was the mean value of weighting each empty tube for 3 times.

Micromotor used to make a hole on the lid of the tube then mesial roots were inserted into the hole and fixed with cyanoacrylate. To keep the balance of air pressure inside and outside of the tubes, a 27-guage needle was inserted in to the lid. The lid was attached back to the tube and the whole apparatus was concealed in a glass bottle with putty, the glass bottle was then covered with black tape to prevent the operator from seeing through while doing the instrumentation process.

The samples were allocated using a random group allocation online software (http://www.randomizer.org) into six groups of fifteen teeth according to the file system (Zenflex and EdgeOne Fire) and the irrigation systems (PUI and MDA) (n=15) used.

2.5 Root canal preparation and irrigation

The mechanical Instrumentation procedures were performed using X-smart Plus motor (Densply Maillefer, Ballaigues, Switzerland). The instrument flutes were cleaned with sterile gauze after 3 passes. The canal was irrigated with 2 ml of distilled water using using a 30G

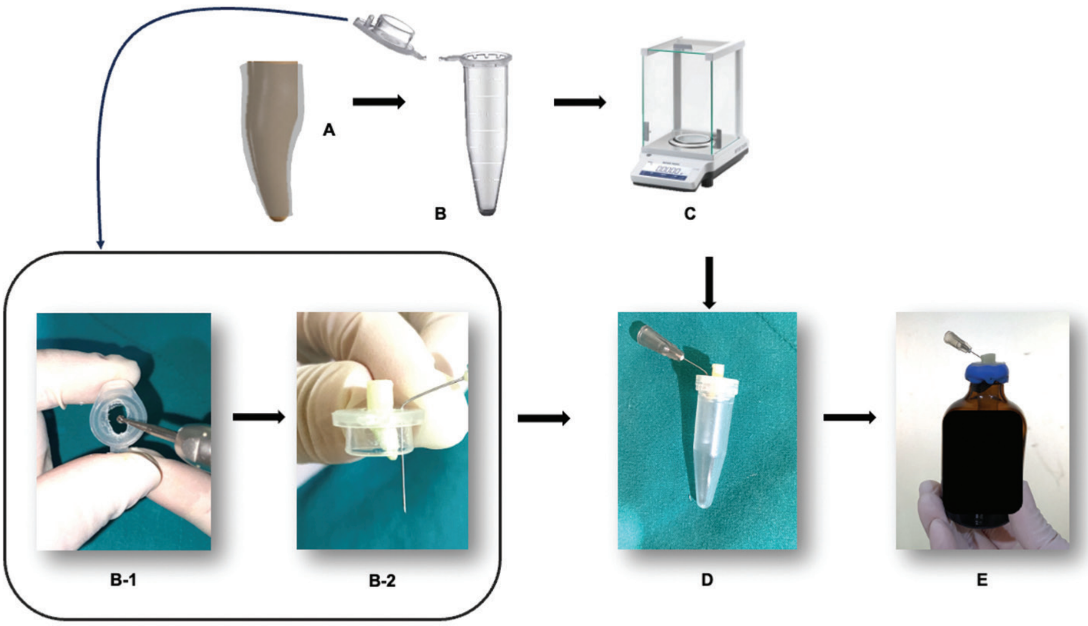

Figure 1: Schematic illustration of the debris collection model modified from Myers and Montgomery (1991).[18] (A), Cyanoacrylate (nail polish) was applied 1 mm above the root apex to seal the apical foramen: (B), The lid of an Eppendorf tube was removed: (B-1), A hole was drilled in the lid to fit each sample, and the sample was sealed in place with cyanoacrylate: (B-2), The sample was inserted up to the mid-root level, and a needle was inserted through the lid to equalize pressure: (C), The Eppendorf tube was weighed without the lid: (D), The prepared lid was securely placed back onto the tube: (E), The tube was fixed to a glass bottle using putty, and the bottle was covered with tape to prevent contamination.

needle with a syringe and size 10 K-file was used to maintain apical patency. These procedures were repeated until the file reached the WL. Total volume of irrigant was limited to 8 ml per tooth.

Group 1: ZF – without adjunctive irrigation

Zenflex™ rotary file size 20 taper 06 to 25 taper 06 were used according to the manufacturer's instruction with a rotational speed of 500 rpm and torque of 2 Ncm. The conventional irrigation using a 30G needle with a syringe with normal saline solution was performed.

Group 2: EOF – without adjunctive irrigation

EdgeOne Fire™ file size 25 taper 07 was used according to the manufacturer's instruction with a 350 rpm speed in 170° CCW and 50° CW direction and completes 360° in 3 cycles.[19] The canal was irrigated in the same manner as in Group 1.

Group 3: ZF + MDA

Zenflex™ rotary file size 20 taper 06 to 25 taper 06 were used, followed by irrigating with MDA technique. With a gentle up and down movement of a gutta percha master cone size 25 taper 04 with the WL-1mm in short 2- to 3-mm strokes with the frequency approximately 100 times per minute (~1.6 Hz) was done.

Group 4: EOF + MDA

EdgeOne Fire™ file size 25 taper 07 was used, followed by irrigating with MDA technique in the same protocol as in Group 3.

Group 5: ZF + PUI

Zenflex™ rotary file size 20 taper 06 to 25 taper 06 were used, followed by PUI technique. An irrisafe with tip size 20 (Satelec Acteon, Merignac, France) was activated at 2 mm short of working length for 1 minute after preparation of canal via Newtron P5® ultrasonic device (Satelec Acteon, Merignac, France) with level 6 of power setting folowing the manufacturer's instruction.

Group 6: EOF + PUI

EdgeOne Fire™ file size 25 taper 07 was used, followed by PUI technique as described in Group 5.

Each rotary file was used for a maximum of four canals and cleaned between uses with sterile gauze, ultrasonic bath (1 min), and microscopic inspection to ensure no debris remained. Instrumentation and irrigation were performed by one operator, while an independent examiner (blinded to the groups) assessed debris extrusion.

2.6 Debris collection and measurement

Following instrumentation, the root was removed from the lid, and any residual debris was rinsed into the Eppendorf tube using 1 mL of distilled water. The tubes were then incubated at 70°C for 5 days to evaporate moisture before weighing the extruded debris. The post-experimental weight (W2) was recorded as the average of three measurements. Debris extrusion was calculated as: (W2-W1).

2.7 Statistical analysis

All the graphs, calculations, and statistical analyzes were performed using GraphPad Prism software version 10.4.1 for MacOS (GraphPad Software, San Diego, CA, USA). The difference of mean weight of extruded debris among all groups were examined using two-way analysis of variance (ANOVA) with Tukey's post hoc test in order to investigate the main effect of each factor (file system and irrigation technique) and interaction effect of both factors on apical debris extrusion. The level of significance was set at $p<0.05$.

Results

The mean ± standard deviation (SD) of apical debris extrusion for each experimental group, along with the results of the two-way ANOVA analysis were demonstrated in Table 1. The analysis revealed a significant main effect of irrigation technique ($F(2,84)=6.965$, $p=0.002$), indicating that the irrigation method significantly influenced the amount of debris extrusion. However, the main effect of file system was not significant ($F(1,84)=0.152$, $p=0.698$), suggesting that the type of file system did not independently affect debris extrusion. Additionally, the interaction effect between file system and irrigation technique was not statistically significant ($F(2,84)=0.911$, $p=0.406$), indicating that the influence of irrigation technique on debris extrusion remained consistent regardless of the file system used.

As illustrated in Figure 2, post hoc multiple comparisons using Tukey's test showed that debris extrusion was significantly lower in groups of both files which PUI was added as an adjunctive irrigation method (Group 5 and 6; mean=0.19±0.17 and 0.19±0.14 µg respectively) ($p=0.020$ and $p=0.017$, respectively) than using EOF file only (Group 2; mean = 0.37±0.13 µg). The combination of PUI regardless of file system (Group 5 and 6) tended to produce less debris extrusion than those groups using MDA technique (Group 3 and 4; 0.28±0.15 and 0.24±0.15 µg respectively) although the statistical significance could not be observed. Furthermore, ZF without supplemental irrigation (Group 1; mean=0.30±0.12 µg) did not exhibit a statistically significant difference in debris extrusion compared to other groups.

Discussion

Apical debris extrusion produced by root canal treatment during mechanical instrumentation and irrigation could caused postoperative flare-ups, inflammation, and delayed periapical healing.[20,21] Previous studies have demonstrated that increased debris extrusion is associated with greater inflammatory mediator release, such as prostaglandins and substance P, which contribute to postoperative discomfort.[22,23] Additionally, residual extruded debris may harbor bacterial biofilms, increasing the risk of persistent apical periodontitis.[24]

In this study, the mesiobuccal canals of mandibular

Table 1: Mean ± SD of debris extrusion (µg) for different file systems and irrigation techniques. Two-way ANOVA results are reported, showing the effects of file system (rotary vs. reciprocating), irrigation technique (w/o irrigation, MDA, PUI), and their interaction. $p<0.05$ is considered statistically significant (**). Abbreviations: w/o = without irrigation, MDA = Manual Dynamic Agitation, PUI = Passive Ultrasonic Irrigation.

File system	Irrigation technique	Mean ± SD	Two-way ANOVA (*p*-value)
ZF	w/o adjunctive	0.30±0.12	File system: 0.698
	MDA	0.28±0.17	Irrigation technique: 0.002 **
	PUI	0.19±0.17	Interaction: 0.406
EOF	w/o adjunctive	0.37±0.13	
	MDA	0.25±0.15	
	PUI	0.19±0.16	

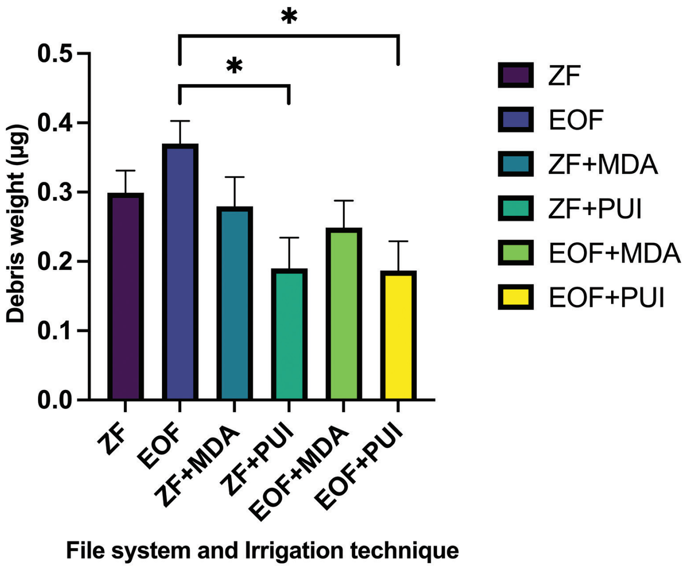

Figure 2: Mean debris extrusion (μg) for different file systems and irrigation techniques. ZF = Zenflex; EOF = EdgeOne Fire; MDA = Manual Dynamic Agitation; PUI = Passive Ultrasonic Irrigation. Error bars represent standard of error (SE). Asterisks (*) indicate statistically significant differences (p<0.05, Tukey's post hoc test).

molars were selected due to their relevance in clinical scenarios where curved canals are commonly found in multirooted posterior teeth. Moreover, curved and complex canals were one of the factors that affected the treatment outcome and the amount of apical debris extrusion.(25) The materials and methods of this study was modified from the study of Myers and Montgomery(18), which was the mainly method used to study the amount of apical debris extrusion after mechanical instrumentation and irrigation. Distilled water was used as the irrigant instead of NaOCl to prevent crystallization and contamination of the debris with sodium crystals.(16,21,26)

The present study evaluated the effects of different file systems (rotary vs. reciprocating) and irrigation techniques (without adjuctive irrigation, MDA, and PUI) on debris extrusion. Two-way ANOVA revealed that irrigation technique had a significant effect on debris extrusion (p=0.002), whereas file system (p=0.698) and the interaction between the two factors (p=0.406) were not significant. These findings suggest that irrigation strategy plays a more critical role in debris extrusion than the choice of file system.

The significant effect of irrigation technique aligns with previous studies demonstrating that PUI significantly reduces apical debris extrusion compared to conventional irrigation methods.(27) The enhanced debris removal with PUI is attributed to its ability to induce acoustic streaming and cavitation, effectively dislodging debris and minimizing its apical extrusion.(28) Additionally, the oscillating motion of the ultrasonic file promotes lateral flow of irrigant along the root canal walls, preventing debris accumulation at the apex.(29) Our post hoc analysis demonstrated that both rotary (ZF) and reciprocating (EOF) file groups using PUI (Group 5 and 6) extruded significantly less debris compared to the EOF without adjuctive irrigation method (Group 2). These findings support the combining PUI as an adjunctive root canal irrigation to optimize debris removal(16) and minimize the risk of postoperative complications associated with extruded debris.(30,31)

In contrast, although no significant differences were observed, the MDA technique tended to produce relatively more debris than PUI when combined with the same file system (Group 3 vs. Group 5 and Group 4 vs. Group 6). This may be attributed to the up-and-down movement of the gutta-percha cone in MDA, which may generate unstable hydraulic forces and push debris beyond the apex. Furthermore, variability in the pumping force applied manually by the examiner may contribute to inconsistent debris extrusion.

Interestingly, the type of file system did not significantly influence debris extrusion. Our results showed that ZF without adjunctive irrigation (Group 1) did not exhibit a significant difference in debris extrusion compared to any other groups. Although mean debris extrusion in Group 1 was lower than that in EOF without adjunctive irrigation (Group 2), this difference did not reach statistical significance (Figure 2). These findings suggest that, while different file kinematics may influence debris extrusion, the effect may not be as substantial as the irrigation technique, which demonstrated a significant impact. The absence of a significant difference between Group 1 and the MDA or PUI groups further reinforces the dominant role of irrigation dynamics over file motion in controlling debris extrusion. This contradicts previous reports suggesting that reciprocating systems generate more extruded debris due to their cutting dynamics and lack of continuous withdrawal motion.[2,3,16] The discrepancies between studies may occur from differences in tooth type, working length, apical diameter, and file size.

The absence of a significant interaction effect between file system and irrigation technique suggests that the beneficial effect of PUI is independent of the instrumentation technique used. This reinforces the idea that irrigation technique exerts a stronger influence on debris extrusion than file kinematics, supporting the prioritization of effective irrigation strategies in clinical practice.

In clinical situation, although there is no study at the present that demonstrate the certain amount of extruded debris that can cause the postoperative complications. While the observed reduction in apical debris extrusion of approximately 0.1 micrograms may seem minor, its clinical significance should not be underestimated. A literature review emphasized that any irritation to periapical tissues, including minimal debris extrusion, may result in flare-ups and impede healing.[22] Therefore, even a small reduction in debris extrusion could potentially decrease the risk of postoperative complications, thereby enhancing patient comfort and treatment success.

A limitation of this study is that the experimental model does not fully replicate the clinical periapical structure, as it lacks the apical resistance typically provided by bone or periapical tissue.[22] Additionally, there were different microhardness of dentin between samples which could affect the difficulty of the instruments while cutting dentin.[32] Future studies could improve upon these limitations by developing more realistic models, such as using gel to mimic an apical barrier or employing micro-CT to collect debris.[26] Further research could also focus on clinical outcomes, such as the incidence of postoperative pain following the use of ZenFlex and EdgeOne Fire combined with MDA and PUI.

Conclusions

With the limitations of the study, our data found that irrigation technique significantly influenced apical debris extrusion, while file system motions had no effect. PUI significantly reduced debris extrusion compared to reciprocating EOF systems without adjunctive irrigation technique. The absence of an interaction effect suggests that irrigation plays a more critical role than instrumentation motion.

Acknowledgments

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Conflicts of Interest

The authors declare no conflict of interest.

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Shear Bond Strength, Tie-wing Fracture Resistance, and Frictional Resistance of a Custommade Ceramic Bracket Version 1

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Abstract

Objectives: Shear bond strength (SBS), tie-wing fracture resistance (Tie-wing FR), and frictional resistance of a custom-made ceramic orthodontic bracket version 1 (CC bracket v1) were evaluated.

Methods: CC bracket v1 and its mould were designed by incorporating average buccal surface-curvature of Thai premolars into its base and fabricated by injection-moulding technique. SBS, Tie-wing FR and static frictional resistance of CC bracket v1 were compared to those of a commercial ceramic bracket (N=10). Normally distributed data were compared between groups using t tests.

Results: SBS means were significantly different between CC bracket v1 and controls (17.25±5.63 MPa and 24.75±5.29 MPa, respectively, $p < 0.05$). Tie-wing FR was significantly lower for CC bracket v1 (41.74±5.34 MPa) than the controls (89.48±15.93). Frictional resistance was significantly greater for CC bracket v1 (141.93±35 gf) vs. controls (86.83±25.4 gf).

Conclusions: CC bracket v1 exhibited lower SBS and Tie-wing FR but clinically acceptable. However, its frictional resistance needs improvement.

Keywords: bracket base, ceramic bracket, fracture resistance, frictional resistance, shear bond strength

Introduction

Concerning in aesthetics has led to an increase in the development of aesthetic orthodontic appliances. The curvature of the base of ceramic orthodontic brackets is generally designed to conform to tooth anatomy. Commercial ceramic brackets mostly have the base curvature conformed to Caucasian tooth surfaces. If they are used in different population, it can result in unprecise direction of forces exerting on the tooth.[1] Thonggerd *et al.,*[2] reported that the average buccal surface curvature of the upper premolars of Thai individuals was less curved than the surface curvature of a commercial bracket base, for which the mean difference reached 0.07558 mm. (Figure 1). The authors described that the occluso-gingival curvature of the tooth differed more than the mesio-distal aspect, which suggested that this difference could affect the precision of torque and rotational movement even though the bracket was bonded in the correct position. In addition, when the bracket base did not conform to the tooth surface, it could result in un-uniform thickness of adhesive at the tooth-bracket base interface which could be a cause of bond failure.[3] Using digital surface scanning technology, a custom-made ceramic bracket can be designed by incorporating the average tooth curvature of specific samples into the bracket base. This should improve the precision of tooth movement and reduce the adhesive thickness, which may result in better interfacial shear bond strength between the tooth and the bracket base.

To address this issue, an initial version of a custom-made aluminium oxide ceramic orthodontic bracket was designed and developed by incorporating mean curvature of buccal surface of upper premolars, derived from Thai samples, into the bracket base.[4] Continuing to the previous study[4], version one of the custom-made ceramic bracket (CC bracket v1) was developed by altering its design while maintaining the curvature of the bracket base as our previous study.[4]

The CC bracket v1 was improved to prevent bracket-wing fracture during fabrication process. It was designed to have more round corners without sharp angles in order to obtain better stress distribution when disengaging its mould during fabrication. To achieve an optimal bond strength, the mechanical retention at the bracket base was increased by adding irregularly shaped aluminium oxide ceramic crystals to the bracket base.

The bracket was made of polycrystalline aluminium oxide ceramic material previously developed by Wasanapiarnpong *et al.,*[5] which offered appropriate mechanical properties for ceramic brackets, including high fracture toughness, transparency, and biocompatibility.

The CC bracket v1 was fabricated using injection-moulding technique and sintering process. A mould of the CC bracket v1 (Figure 2) was developed by an engineering team at the Thai-German Institute of Technology using a reverse engineering process. To enhance the success rate of fabrication and prevent fracture of the bracket wings during disengagement of the mould pieces, a custom-made mould was designed. This stainless steel mould also accounted for 25% shrinkage of the ceramic material during the sintering process.[4] This study extended the benefits of surface-scanning technology to develop custom-made ceramic orthodontic brackets for use in individuals or specific populations in the future.

Adequate bond strength to tooth surface, high fracture toughness of the tie-wings of the brackets, and low frictional resistance to the wires are considered basic mechanical requirements of the orthodontic ceramic brackets. The objectives of this study were to compare the mechanical properties of CC bracket v1 and a commercial ceramic bracket in terms of shear bond strength (SBS), tie-wing fracture resistance (Tie-wing FR), and static-frictional resistance (S-FR).

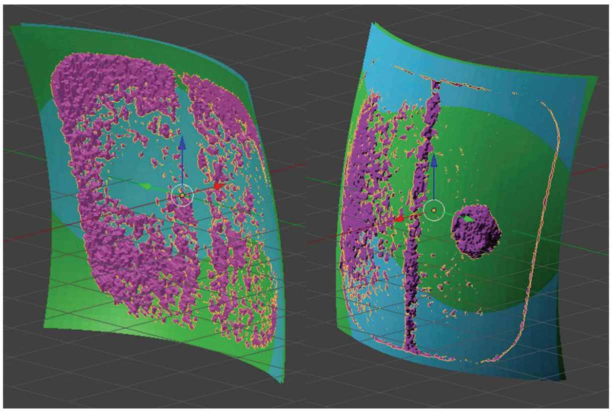

Figure 1: The difference between the average curvature of the buccal surface of the upper premolars of samples from Thai individuals (blue) and curvature of the commercial bracket base (green and purple). Purple represents the rugged curvature of the real base in the commercial ceramic bracket, whereas green represents a commercial bracket's curvature in a fit curve pattern closely resembling the ultimate curvature of the purple.

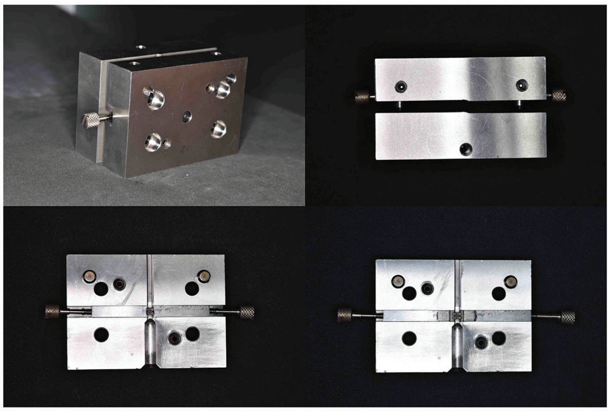

Figure 2: The metal mould of CC bracket v1. There are two separating compartments with handles that can be pulled apart to prevent ceramic bracket fracture during fabrication.

Materials and Methods

Fabrication of the custom-made ceramic bracket version 1

The material composition of the CC bracket v1 consisted of magnesium aluminium oxide ($MgAl_2O_4$), polyethylene glycol (PEG), polyvinylbutyral, and stearic acid. These components were mixed in two cycles and compressed using an injection-moulding technique to obtain the desired shape. The process began by injecting lubricating oil into the mould, which was heated to 200 degrees Celsius. The mixture was then injected into the mould at a temperature of 210 degrees Celsius. The mould was cooled to room temperature, and the brackets were carefully removed from the mould. The brackets were soaked in distilled water for 24 hours to dissolve the remaining PEG.

To enhance the retention property of the bracket base, a mixture of 100-300 nm $MgAl_2O_4$ powder and ethanol at a 50:50 ratio by weight was prepared. The mixture was applied to the base of the bracket using a fine-tip brush under a 10X magnifying scale loupe. After allowing the ethanol to completely evaporate, the bracket was heated at approximately 500 degrees Celsius for one hour to remove the remaining binders. The temperature was raised to 1,650 degrees Celsius at a rate of 5 degrees Celsius per minute and maintained for 2 hours before allowing the bracket to cool naturally in an electric furnace. Then, the bracket was removed from the electric furnace, and the external surfaces were polished with a superfine diamond bur.

Mechanical properties

Shear bond strength test

The SBS test was performed according to Thonggerd *et al.,*[(4)] and Suliman *et al.,*[(6)] This research was approved by the University Human Ethics Committee (SWUEC-384/2564X). Twenty unidentified upper premolars were anonymously collected from a hospital and dental clinics and were kept in accordance with the standards of ISO 3696:1987. Inclusion criteria of the samples was a sound tooth with a definite cemento-enamel junction. The exclusion criteria for sample collection were enamel cracks, any signs of caries, abfraction, abrasion, an enamel craze line, enamel hypoplasia, demineralization, or fillings on the crown or root.[(7)]

The tooth samples were prepared by mounting the root in 1×1×1 inch^3 dental die stone blocks that were allowed to set completely in a humidified box.

The samples were randomly divided into 2 groups (10 teeth per group). Group 1 included CC brackets v1, and Group 2 served as the control group (a commercial ceramic brackets with 022” slot; Clarity Advanced™, 3M Unitek, Monrovia, USA). The tooth surfaces were polished, etched with 37% phosphoric acid (3M Unitek) for 30 seconds[(4)], and air-blown until a chalky white appearance was revealed. The primer was applied (Transbond XT™, 3M Unitek, Monrovia, USA) on the tooth surface and air-thinned for 10 seconds. An adhesive bonding agent (Transbond XT™, 3M Unitek, Monrovia, USA) was applied to the tooth surfaces and at the bases of the brackets. The brackets were positioned on the tooth surfaces in the middle of the crown in occluso-gingival and mesio-distal dimensions. The brackets were placed with a hand instrument and pressed with 5 N force, which was measured using a force gauge. The excess adhesive was removed, and the adhesive was cured with LED light (Mini-LED Satelec, Acteon, Mount Laurel, USA) for 20 seconds on each side.[(4)] After bonding, the specimens were stored in 37°C distilled water[(4,6)] for 24 hours before testing.

The specimens were fixed on a stand of a universal testing machine (EZ test, Shimadzu, Japan), and the level of the bracket’s wing was aligned parallel to the direction of the applied force and knife-edge blade of the testing machine (Figure 3). The SBS was tested at a cross-head speed of 1 mm per minute[(4)] until the bonding between the bracket and the tooth surface was broken. The failure load was recorded and reported as megapascals by dividing the failure load value by the surface area of the bracket base. After the SBS test, all specimens were evaluated using the adhesive remnant index (ARI)[8] obtained using optical microscopy at a magnification of 20. The failure load and ARI score were statistically analysed.

ARI index was categorized into 0-3 scores, as follows:

- 0, no adhesive left on tooth
- 1, less half of the adhesive left on the tooth
- 2, more than half of the adhesive left on the tooth
- 3, all the adhesive left on tooth with mechanical pattern visible[8]

Tie-wing fracture resistance test

Tie-wing FR was tested using methods adopted from Thonggerd *et al.,*[4] and Johnson *et al.,*[9] Ten samples from Group 1 (CC bracket v1) and Group 2 (controls) were tested and compared.

Each bracket was fixed on acrylic blocks with resin adhesive (Transbond XT™, 3M Unitek) (Figure 4A) and attached to a platform of the testing machine. The ceramic bracket was held with a 0.012-inch ligature wire at the horizontal slot (Figure 4B). The retention of specimens was enhanced by embedding the gingival part of the bracket into the acrylic resin (Figure 4C). Disto-incisal wing of the bracket was tied with a 0.012-inch ligature wire, and both ends were attached to the loading part of the universal testing machine (Figure 4D). The Tie-wing FR was measured in tensile mode at a cross - head speed of 10 mm per minute until the bracket wings fractured (Figure 4E). The tensile force value was recorded in Newtons and converted to megapascal by dividing the failure load value by the contact area between the ligature wire and the tie-wings.

Frictional resistance test

The static frictional resistance (S-FR) test was modified from Jian-Hong Yu *et al.,*[10] and Tribumrungsuk *et al.*[11] Ten samples from Group 1 (CC bracket v1) and Group 2 (controls) were tested. The S-FR between the slot surface of the ceramic bracket and the 7 cm length of 0.019”×0.025” stainless steel wire was recorded with a universal testing machine.

Each ceramic bracket was fixed on a metal plate, positioned at a mark point and a jig to ensure that the wire and the bracket slot were parallel to each other with 0-degree torque, and then ligated with an elastomeric ring (3M Unitek). The upper end of a 0.019”×0.025” stainless steel wire was attached to the upper compartment of the testing machine (Figure 5).

After the specimen was prepared, the machine pulled the wire through the bracket slot using a 50 N load cell and a crosshead speed of 2 mm per minute. The frictional force–displacement curve was plotted, and the peak of the static frictional force was recorded and statistically evaluated.

Scanning electron microscopy (SEM)

The bracket surface was attached to the sample base and coated with gold. The surface of each bracket was analysed using SEM (JSM, 6480LV, JEOL™) to investigate the grain size, shape, homogeneity of the $MgAl_2O_4$ crystals, and the bracket surface roughness.

Data analysis

Statistical analysis was performed using SPSS version 27.0 (SPSS Inc., Chicago, Illinois, USA). Shapiro–Wilk test results showed that the data were normally distributed, differences between the two groups were analysed using the independent t test. The chi-square test was used to compare the ARIs of each group. The statistical significance level was set at $p<0.05$.

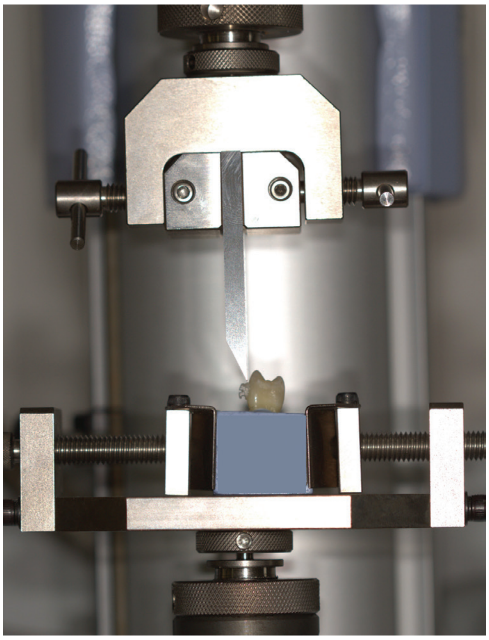

Figure 3: The shear bond strength test was performed using a universal testing machine (EZ test, Shimadzu, Japan) at a cross - head speed of 1 mm per minute.

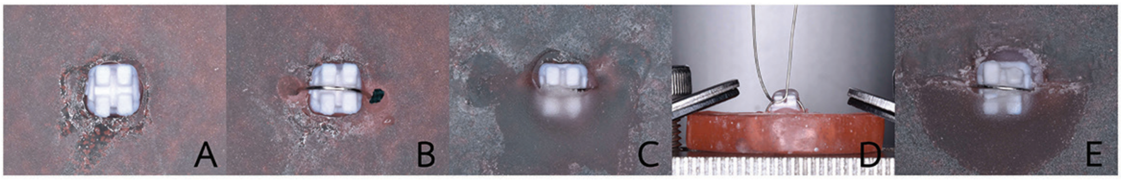

Figure 4: The specimen preparation process (A-C) and the Tie-wing fracture resistance test using a universal testing machine (D and E) (EZ test, Shimadzu, Japan).

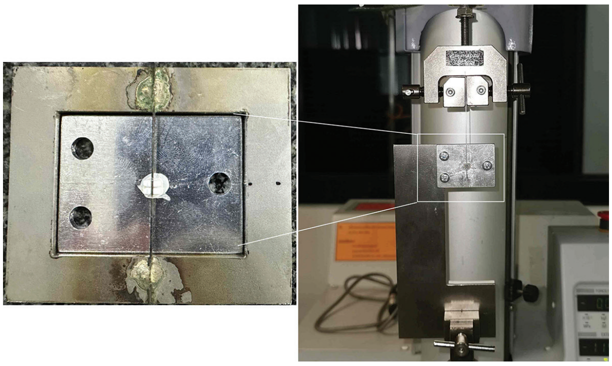

Figure 5: Frictional resistance was tested using the universal testing machine (EZ test, Shimadzu, Japan).

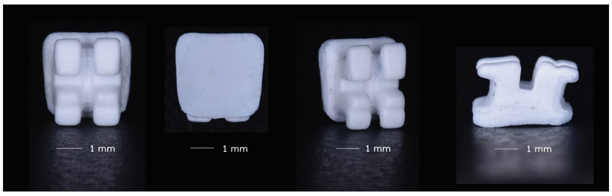

Figure 6: The custom-made ceramic bracket version 1.

Results

Fabrication of the custom-made ceramic bracket version 1

The CC bracket v1 showed no excess ceramic beneath the tie-wing area, and the horizontal slot size was appropriate for a 0.019”×0.025” stainless steel wire (Figure 6).

Mechanical properties

Shear bond strength and ARI tests

The SBS means of Group 1 (CC bracket v1) and Group 2 (controls) were 17.25±5.63 MPa and 24.75±5.29 MPa, respectively. Statistical analysis indicated a significant difference ($p<0.01$) in the SBS between the two groups (Table 1). Group 2 showed patterns of debonding with ARI scores ranging from 1 to 3, whereas the ARIs of Group 1 ranged from 2 to 3. A score of 3 was the most frequently observed in Group 1. Statistical analysis indicated no significant difference in the ARI scores between the two groups ($p>0.05$) (Table 2).

Tie-wing fracture resistance

The means of the Tie-wing FR of Group 1 (CC bracket v1) and Group 2 (controls) were 41.74±5.34 MPa and 89.48 ± 15.93 MPa, respectively. Statistical analysis indicated a significant difference ($p<0.001$) in Tie-wing FR between the two groups (Table 3).

Static frictional resistance

The mean S-FR of Group 1 (CC bracket v1) was 141.94±35 gm, whereas Group 2 (controls) had a mean S-FR of 86.83±25.4 gm. Statistical analysis revealed a significant difference ($p<0.001$) in the static frictional resistance between the two groups (Table 4).

Scanning electron microscopy (SEM)

SEM evaluation revealed that the crystals at the base of the commercial ceramic bracket were larger in size than the $MgAl_2O_4$ crystals found on the base of CC bracket v1 (Figure7). SEM analysis of the surface roughness revealed that the commercial ceramic bracket had grain sizes mostly less than 10 µm, whereas CC bracket v1 had grain sizes exceeding 50 µm (Figure 8).

Discussion

Fabrication of the custom-made ceramic bracket version 1

Digital technology can be applied to the manufacturing of orthodontic appliances. This study aimed to incorporate scanning surface technology to design a custom-made ceramic bracket with a base that has anatomical curvature conforming to a group sample from a specific population. The injection mould used to produce the custom-made ceramic bracket was constructed using reverse engineering and 3D printing of stainless steel. The ceramic injection and sintering processes used to fabricate the

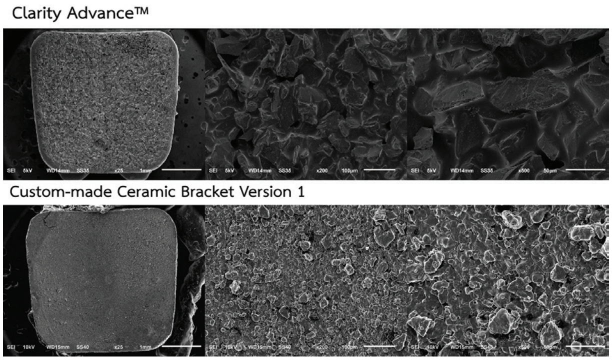

Figure 7: Surface of bracket base of the commercial ceramic bracket and the CC bracket v1 in magnification of 25×, 200× and 500×. The crystals at the base of the Clarity bracket were larger in size compared to the $MgAl_2O_4$ crystals found on the CC bracket base.

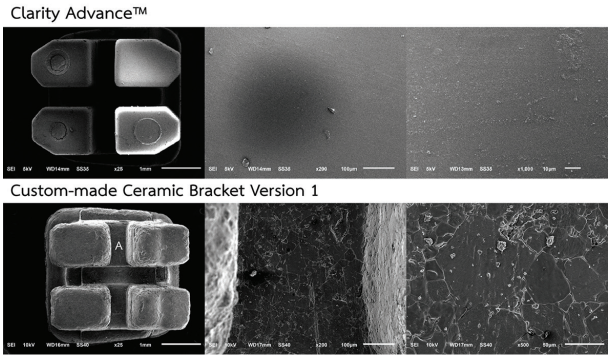

Figure 8: Surface roughness of the commercial ceramic bracket and the CC bracket v1 (Bracket slot; A) at 25×, 200× and 500× magnification.

Table 1: Comparison of the SBS means between CC bracket v1 and the controls (Clarity Advance™).

	Cross section area of bracket base (mm^2)	Mean SBS (MPa)	Range (MPa)	*p*-value
Group 1 (CC bracket v1)	12.8	17.25±5.63	7.51-26.86	.008**
Group 2 (Controls: Clarity Advance™)	11.69	24.75±5.29	18.14-31.33	

**$p<0.01$, independent *t*-test

Table 2: Comparison of the ARI scores between CC bracket v1 and the controls (Clarity Advance™).

ARI score	0	1	2	3	*p*-value
Group 1 (CC bracket v1)	0%	0%	25%	75%	.074
Group 2 (Controls: Clarity Advance™)	0%	37.5%	37.5%	25%	

*$p>0.05$, Chi square *t*-test

Table 3: Comparison of mean tie-wing fracture resistance between the CC bracket v1 and the controls (Clarity Advance™).

	Mean fracture resistance (N)	Area of touched wire (mm^2)	Mean fracture resistance (MPa)	Range (MPa)	*p*-value
Group 1 (CC bracket v1)	16.69±2.17	0.4	41.74±5.34	32.1-51.86	.000***
Group 2 (Control: Clarity Advance)	35.79±6.38	0.4	89.48±15.93	68.73-115.05	

***$p<0.001$, Independent *t*-test

Table 4: Showed comparison of means static frictional resistance between the CC bracket v1 and the controls (Clarity Advance™).

	Mean of Frictional Resistance (gm)	Range (gm)	*p*-value
Group 1 (CC bracket v1)	141.94±35	92.05–189.36	.000***
Group 2 (Controls: Clarity Advance™)	86.83±25.4	54.15–148.34	

***$p<0.001$, Independence *t*-test

custom-made bracket can be performed in an in-house laboratory. This study showed the potential benefits of digital technology for the fabrication of custom-made ceramic brackets for individuals in the future.

A limitation of this study is the absence of a validated method to accurately assess whether the curvature of the base conforms to the mould, which should be addressed in future research.

Shear bond strength

Adequate shear bond strength between the bracket base and tooth surface is pivotal for the delivery of effective forces in orthodontic treatment. A higher SBS is not always favourable; on the other hand, an optimal bond strength is preferred to prevent premature loss of the brackets as well as to prevent enamel loss in the debonding process.(6) According to a study by Reynold(12), the minimum SBS required for successful clinical orthodontic bonding was 5.88-7.85 MPa. Zepperi *et al.,*(13) reported that the clinically acceptable SBS ranged from 13 to 21 MPa. The results of this study showed that the average SBS of CC bracket v1 was greater than the minimum clinically acceptable SBS reported by Reynold(12) and within the clinically acceptable range reported by Zepperi *et al.*(13)

The debonding pattern revealed by the ARI index analysis indicated that the debonding stress of CC bracket v1 was concentrated at the interface between the bracket base and adhesive material (ARI-2, ARI-3). In contrast, given the higher SBS in the Clarity Advance group, the debonding stress was equally concentrated at the bracket base–adhesive interface (ARI-2=37.5%) and enamel–adhesive interface (ARI-1=37.5%), which could increase the risk of enamel damage during bracket debonding. According to Retief *et al.,*(14) 13.5 MPa was the minimum bond strength at which enamel damage could occur during the debonding process. This study showed that the average SBS of the Clarity Advance was greater than 13.5 MPa, so bond failure at the enamel–adhesive interface was frequently observed, indicating good bonding to enamel but a greater risk of enamel loss. Although there was no statistically significant difference in the ARI values between the two groups, ARI-3 was the most frequently observed in the CC bracket v1 group (ARI-3= 75%). These findings suggested that the CC bracket v1 could contribute to a lower risk of enamel damage during debonding but still had a clinically acceptable SBS.

The shear bond strength between ceramic bracket and enamel can be affected by many factors, including the pattern and size of the bracket base.(15-17) A previous study(4) suggested that the irregularity and consistency of $MgAl_2O_4$ crystals at the bracket base might affect the bond strength. SEM analysis revealed that the crystal particles at the base of CC bracket v1 were irregular in shape. Large crystals at the CC bracket v1 base provided extensive undercuts or irregularities on the surface. These undercuts offered additional surface area for the adhesive resin to mechanically interlock and form a stronger bond with the tooth surface, leading to optimum SBS. Studies of ceramic bracket base designs(15-16) reported that a bracket with 50 μ-round glass particles incorporated onto its alumina base showed the highest SBS of 24.7±1.9 MPa. The results suggested that these beads had adequate undercuts for mechanical interlocking of the adhesive resin, which could increase the bonding ability. Based on the SEM study (Figure 7), the crystals at the base of the Clarity bracket were larger in size than the $MgAl_2O_4$ crystals found on the base of the CC bracket v1. Specifically, the average size of the crystals in the Clarity bracket base was within the range of 20 to 100 μm, whereas the average size of the crystals in the CC bracket v1 base was less than 25 μm. Therefore, discrepancies in the crystal sizes could be a factor involved in the lower SBS observed in CC bracket v1. The next version of the CC bracket base might be improved by increasing the size of the $MgAl_2O_4$ crystals to create more undercuts for mechanical retention and to enhance the optimal SBS of the bracket.

A study by Newman(17) reported that a larger bracket base led to increased bond strength. The size of the bracket base of CC bracket v1 was 12.8 mm^2, which was larger than the size of the Clarity Advance bracket (11.69 mm^2). However, the results of this study did not correspond to those of the study by Newman.(17) Thus, the irregularity of the crystalline grains of ceramic materials at the bracket base might have a greater effect on SBS than the surface area of the bracket base.

Apart from shear bond strength, dissimilarity of the occluso-gingival aspect of the curvature between the commercial ceramic bracket base and the buccal surface of the upper premolars of Thai individuals could impact torque and rotational movement.(2) Nevertheless, effects of differences between various types of bracket base including that of the CC bracket v1 and the anatomical surface of a tooth on torque and rotational movements should be further investigated in future studies.

Tie-wing fracture resistance

Ceramic bracket fractures are associated with material property of aluminium oxide to withstand multiple direct forces. Resistance to breakage additionally relies on the specific type, shape, grain size, overall volume, and quality of the manufacturing process of the ceramic brackets.[18-27]

Sharp outlines and pointed angles at the corner of the ceramic brackets could increase stress at the concentrating area of the torque and tip when a controlled force is applied.[9,18,19] Fractures usually occur at the tie wings and the inner slot[19]; thus, the bracket design of the tie wings and the inner slot is important for improving the fracture toughness of ceramic brackets.[19,20] CC bracket v1 was designed to have round corners and few sharp angles. However, the average tie-wing fracture resistance of CC bracket v1 was significantly less than that of the control group (41.74±5.34 and 89.48±15.93, respectively, $p<0.001$). Although this bracket design did not improve the Tie-wing FR, it could still withstand the fabrication process by preventing bracket wing fractures during disengagement from the mould.

Another important factor for the fracture resistance of a ceramic bracket is the grain size of the ceramic material. Larger grain sizes, especially those exceeding 5 μm, tend to reduce ceramic strength.[21-23] According to the SEM study, the commercial ceramic bracket was composed of grain sizes less than 10 μm, whereas the CC bracket v1 was composed of materials with grain sizes that exceeded 50 μm. This significant difference in grain size could contribute to the lower tie-wing fracture resistance of CC bracket v1 compared to that of the controls.

The fracture toughness of the bracket wing could be influenced by the thickness of the ceramic material. According to the critical load equation, the critical load varied with the square of the ceramic layer thickness[24-25], meaning that the strength of the bracket wing was affected by its dimensions. The wing of the CC bracket v1 was 0.2 mm thinner than that of the controls in all three dimensions. This difference in thickness could result in a reduced fracture resistance of the tie-wing of CC bracket v1. However, to our knowledge, no previous study has quantified an impact of different thickness on tie-wing fracture resistance. Therefore, it is suggested for future investigation.

Defects, such as voids and microcracks, occur during the custom manufacturing process[18,26], contributing to a reduction in the fracture resistance of CC bracket v1.[24,26-27] SEM analysis revealed the presence of pores in CC bracket v1, which could result in a lower tie-wing fracture resistance than that of commercial ceramic brackets.

When considering the ligating force to a bracket, the average Tie-wing FR of the CC bracket v1 (16.69±2.17 N) was still greater than the average elastomeric ligation force (3.6-5.3 N) reported by Nakhaei *et al.*[28] For the development of future versions of the CC bracket, in addition to the reduction of porosity, it might be necessary to decrease the grain size and increase the size of the wings.

Frictional resistance

Previous studies reported that the frictional resistance of ceramic brackets was greater than that of stainless-steel brackets. The frictional resistance of the slot of the bracket was caused by the high coefficient of friction of the ceramic material and increased by the rough surface condition.[29] To our knowledge, no study has reported clinically acceptable frictional resistance for fixed orthodontic brackets. Compared to previous studies[30-33] in which the frictional resistance of polycrystalline ceramic brackets (0.022”× 0.028”-slot) was tested with 0.019”×0.025” stainless steel wire and ligated with a clear elastomeric ring, the average static frictional resistance of CC bracket v1 (141.93±35 gf) was greater than that of Clarity Advance, 3M Unitek™ (86.83±25.4 gf), Signature, RMO™ (114.1±22.8 gf)[31] and Reflection, Ortho Technology™ (118.6±52.5 gf)[32] but less than that of Transcend series 6000, 3M Unitek™ (152.5±53.6 gf)[33] and Illusion plus, Ortho Organizers™ (230.45±0.21 gf).[30] The average frictional value of the CC bracket v1 was found to be the closest to those of the Transcend series 6000, 3M Unitek™. SEM revealed that the surface of CC bracket v1 exhibited greater irregularity than that of the controls, which is consistent with the findings of a previous study.[19] However, higher frictional resistance of the CC bracket v1 may affect the efficiency of tooth movement, further studies should be investigated in the future.

The manufacturer of the Clarity Advance reported that its bracket slot was coated with yttria-stabilized zirconia to reduce friction. In addition, a study reported that coating a slot with a silica layer could also reduce the frictional resistance.[34] These techniques can be used to improve the frictional resistance of CC bracket v1 in the future.

Conclusions

1. The CC bracket v1 was designed to incorporate the average curvature of the upper premolars of the Thai population onto the bracket base. It can be fabricated in an in-house laboratory using the injection-moulding technique and sintering.

2. The SBS of the CC bracket v1 was lower than that of the controls but clinically acceptable.

3. Although the Tie-wing FR of the CC bracket v1 was less than that of the controls, it was greater than the elastic ligature tying force to the bracket wings.

4. The frictional resistance of CC bracket v1 was greater than that of the controls but comparable to that of other commercial ceramic brackets.

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Original Article

Evaluation of Microtensile Bond Strength Between Biodentine and Post Cement at Different Time Intervals

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Abstract

Objectives: To investigate the microtensile bond strength (µTBS) of various adhesive systems (etch & rinse, self-etch, and self-adhesive) for bonding MultiCore Flow and Biodentine at different time intervals.

Methods: Sixty pairs of 7x7x3 mm resin-based 3D-printed blocks with a 1x1 mm central tube were used in this study. One side of the blocks was filled with Biodentine, while another side was filled with MultiCore Flow. The materials were bonded using one type selected from these adhesive systems: ExciTE F DSC (etch & rinse), Multilink N (self-etch), or RelyX U200 (self-adhesive). Each group was subdivided into immediate and delayed groups (n=10). Specimens were subjected to µTBS testing, and failure modes were observed under a stereomicroscope. Two-way ANOVA was used to analyze the influence of time and adhesive system on µTBS.

Results: The results revealed that Multilink N group showed significantly higher µTBS in the immediate group compared to the delayed group (p=0.01). When comparing the materials, ExciTE F DSC performed significantly worse than Multilink N (p=0.02) and RelyX U200 (p=0.04) in the immediate group. The predominant failure modes observed under the stereomicroscope were mixed failure and cohesive failure within Biodentine.

Conclusions: Immediate placement of adhesives and MultiCore Flow over Biodentine showed higher microtensile bond strength than delayed placement. Overall, self-adhesive systems demonstrated high bond strength at both time intervals. Immediate bonding with self-adhesive systems may enhance the bond strength between Biodentine and MultiCore Flow in clinical practice, potentially leading to improved restoration longevity and reduced risk of failure.

Keywords: biodentine, cement, failure mode, microtensile bond strength, post

Introduction

Root canal treated teeth often have a significant loss of structural integrity. Consequently, after root canal treatment, it becomes necessary to place a post within the root canal as part of the restorative process. The primary purpose of a post is to serve as a retention for the core build-up material.(1) Additionally, a well-placed post contributes to a more intimate seal between the restorative material and the root canal. Studies conducted by Ray & Trope in 1995(2) and Tronstad *et al.,* in 2000(3) have demonstrated that the quality of root canal filling and restoration directly influences the long-term success rate of the treated tooth. Root canal filling materials, such as gutta-percha with sealer, are typically used in simple root canal treatment cases. However, more complex cases, including open apices and perforations, may require alternative materials. Hydraulic calcium silicate-based cements like Biodentine (Septodont, St. Maur-des-Fossés, France) have emerged as promising options for these situations. Biodentine possesses chemical and physical properties that make it an ideal material for root canal repair. It also demonstrates a short setting time and strong adhesive properties to dentin, making it a suitable restorative material for dentin.(4,5) Case reports have documented the successful use of Biodentine for apexification in a single visit, replacing the traditionally used MTA (mineral trioxide aggregate; Dentsply Tulsa Dental, Tulsa, OK, USA), which has a longer setting time.(6,7) Furthermore, a study by Yadaw *et al.,* in 2020(8) evaluated the single-visit obturation of necrotic immature permanent teeth with Biodentine and reported a 100% success rate at a 9-month follow-up.

Following endodontic procedures, resin composite core materials, MultiCore Flow (Ivoclar Vivadent, Schaan, Liechtenstein), are commonly used for post placement and core build-up. When placing a post within a root canal, an interface is created between two materials: hydraulic calcium silicate cement and post cement. Various adhesive systems are commonly used to bond these two surfaces. Contemporary adhesive systems include etch-and-rinse system such as ExciTE F DSC (Ivoclar Vivadent) and OptiBond FL (Kerr Corporation, Brea, CA, USA), self-etch system such as Multilink N (Ivoclar Vivadent) and Panavia V5 (Kuraray Noritake Dental Inc., Tokyo, Japan), and self-adhesive system such as RelyX U200 (3M ESPE, Deutschland GmbH, Neuss, Germany) and G-Cem LinkAce (GC Corporation, Tokyo, Japan). These adhesive systems have been widely used as post cements in clinical practice.

Posts placed within root canals typically have a snug fit, limiting lateral movement. Therefore, the primary forces experienced by the restoration are vertical. These vertical forces, akin to tensile strength, may lead to debonding at the interface between Biodentine and post cement. Additionally, the setting reaction between Biodentine and the adhesive system may influence bond strength. Moreover, the material's stiffness can affect bond strength. Some studies have examined bond strength between Biodentine and adhesive systems, such as the study by Hardan *et al.,*(9) which found that both self-etch and total-etch strategies exhibited promising bonding performance with Biodentine. However, there is a lack of study on the microtensile bond strength of these materials, which should be elucidated. Therefore, this study addresses this gap by using standardized 3D-printed blocks to compare the microtensile bond strength of three different adhesive systems to Biodentine.

This study aimed to investigate the microtensile bond strength (μTBS) between Biodentine and MultiCore Flow using various types of adhesive systems at different time intervals.

Material and Methods

Sample size calculations was determined from a similar study using this formula (Figure 1).(10,11) With α level type I error at 0.05 and β level type II error of 0.20 for the study, a sample size of 10 were obtained for each group.

$$n/gr = \frac{2(Z_{\alpha} + Z_{\beta})^2 \sigma^2}{(\mu_1 - \mu_2)^2}$$

Figure 1: The formula of calculating sample size.

Sixty sets of 3D-printed clear resin blocks (120 pieces of blocks and 60 pieces of covers) were meticulously designed using Google SketchUp 2020 software (Google LLC., Mountain View, CA) and printed using a 3D Printer called Pro 55 (SprintRay, Los Angeles, CA), with surgical guide resin, which utilized DLP processing. The transparency of the resin blocks facilitates complete light transmission, ensuring full curing and polymerization of the material. The manufacturer's guidelines were followed to ensure precision and consistency in the fabrication process.

The block was designed with 7x7x3 mm^3 in size. These blocks featured a central tube with dimensions of 1x1 mm^2, extending along the length of the block. When paired, the central tubes from each block interconnected to form a continuous 14 mm long tube. To minimize material leaking, small gaps were incorporated between the "connecting end" of the blocks. The opposite end, referred to as the "application end", served as the entry point for introducing material into the block.

The cover was designed to prevent movement and stabilize a pair of blocks. It is 18x11x3 mm^3 in size. The cover had a 2-millimeter reinforcement on the edges of its width and length for added strength, while the base of the cover is 1-mm thick. The internal size with a dimension of 14x7x2 mm^3 were specifically tailored to accommodate the blocks securely. This would cause the blocks to protrude approximately 1 mm above the cover. The cover also featured a 3 mm^2 opening at each end, corresponding to the dimensions of the opening in the central tube of the blocks for material application. Additionally, a 3 mm^2 opening was located at the center of the base for observation during experiments and easy removal of the blocks (Figure 2).

Prior to use, each block was undergone thorough cleaning and subjected to an additional round of ultrasonic cleaning to ensure optimal sterility and cleanliness, thus maintaining the integrity of the experiment, and minimizing potential contamination. Then, the blocks were paired within the cover, with the connecting ends aligned towards each other. The connecting ends were ensured to fit snugly within the cover, forming a perfectly interconnected tube.

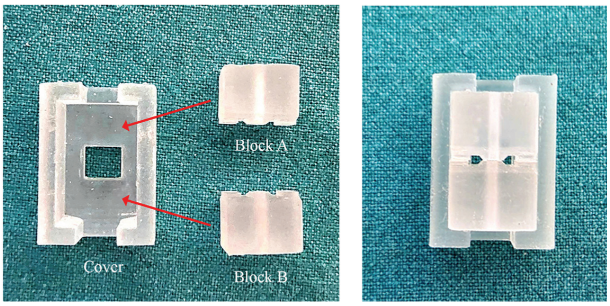

Figure 2: 3D-printed resin block and cover. (Left) Disassembled components, with arrows indicating the insertion of Block A and Block B into the cover. (Right) Assembled unit, showing the cover stabilizing and aligning the blocks for specimen preparation and testing.

The 60 sets of blocks were equally divided into three groups based on the adhesive system used: ExciTE F DSC (Etch & rinse), Multilink N (Self-etch), and RelyX U200 (Self-adhesive). Each group was further subdivided into two subgroups according to the timing of adhesive material placement on Biodentine. In the immediate group, blocks were paired with MultiCore Flow immediately after Biodentine's initial setting (approximately 12 minutes). In the delayed group, blocks were paired with MultiCore Flow after a full 14-day Biodentine setting period.

Biodentine was carefully inserted into each individual block within a set. An endodontic plugger (RCP5/7; Hu-Friedy, Chicago, IL, USA) was used to compress the Biodentine within each block to a consistent thickness of approximately 2 mm. Finally, the paired resin blocks were combined to form the complete set.

Different adhesive systems were applied to Biodentine's interface according to their respective groups: ExciTE F DSC (etch-and-rinse), Multilink N (self-etch), and RelyX U200 (self-adhesive). For each adhesive system, the surface of the resin block was prepared according to the manufacturer's recommended protocol. MultiCore Flow was then applied to achieve a uniform 2-mm thickness to the prepared hole of the other resin block. This prepared block was then connected to the Biodentine block at the varying time intervals described earlier. Subsequently, the MultiCore Flow was light-cured through the resin block using Bluephase N® LED light-curing unit (Ivoclar Vivadent) at HIGH-mode for 20 seconds to ensure complete polymerization at the interface. Subsequently, the samples were incubated at 37°C and 99% humidity for 7 days before undergoing the µTBS test.

After a 7-day incubation, the prepared 3D-printed resin blocks were securely attached to the brass gripped testing fixtures using cyanoacrylate adhesive (Loctite 416; Henkel Corp. Connecticut, USA) to establish a firm connection for testing, The cover was removed prior to the test. Subsequently, µTBS was assessed using an Instron® 5566 universal testing machine (Instron Engineering Corporation, Norwood, MA, USA) at a crosshead speed of 1 mm per minute (Figure 3). The maximum force at failure was recorded in Newtons (N) and the µTBS values were calculated in megapascals (MPa; newton/mm^2) by dividing this force by the cross-sectional area of the bonded region (1 mm^2).

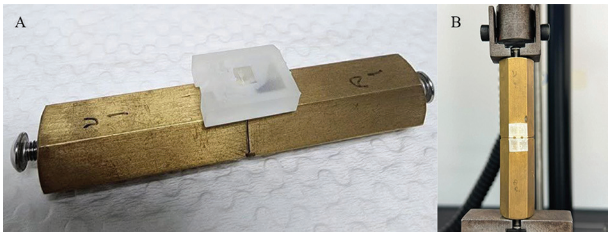

Figure 3: Specimen preparation and µTBS testing. (A), A 3D-printed resin block set (with bonded Biodentine and MultiCore Flow) was attached to the brass testing fixture using cyanoacrylate adhesive: (B), After attachment, the cover was removed, and the specimen was mounted in the universal testing machine for µTBS measurement.

The fractured surfaces of specimens were examined under a 40x stereoscopic microscope (Olympus Corp. Tokyo, Japan) to analyze and categorize into four types of failure modes according to the following criteria:

- Adhesive failure: This occurs entirely between the layers of Biodentine and MultiCore Flow.
- Cohesive failure in Biodentine: This occurs entirely in Biodentine.
- Cohesive failure in MultiCore Flow: This occurs entirely in MultiCore Flow
- Mixed failure: This involves fractures both in Biodentine and MultiCore Flow, as well as between the layers of Biodentine and MultiCore Flow.

The results were presented as mean ± standard deviation (SD) and were subjected to statistical analysis using SPSS 25.0 software (SPSS Inc, Chicago, IL, USA). The µTBS values were assessed for normal distribution using the Shapiro-Wilk test. A two-way analysis of variance (ANOVA) was conducted to assess the presence of significant differences in µTBS values between the groups.

Results

The microtensile bond strength testing

In the immediate group, Multilink N showed the highest µTBS values (18.81±6.61 MPa) compared to RelyX U200 (17.95±4.13 MPa) and ExciTE F DSC (10.66±4.07 MPa). However, in the delayed group, Multilink N showed the lowest µTBS values (6.95±3.76 MPa) compared to ExciTE F DSC (8.39±1.60 MPa) and RelyX U200 (12.26±6.34 MPa).

Within each material group, the delayed subgroups consistently showed lower µTBS values than the immediate subgroups. However, statistical analysis revealed a significant time-dependent effect only in the Multilink N group (p=0.01). Moreover, when comparing material groups, ExciTE F DSC revealed significantly worse than Multilink N (p=0.02) and U200 (p=0.04) in the immediate group. On the contrary, no significant differences were observed among the materials in the delayed group (p>0.05) (Figure 4).

Failure mode distribution

The most common failure modes observed were mixed failures and cohesive failures in the Biodentine in

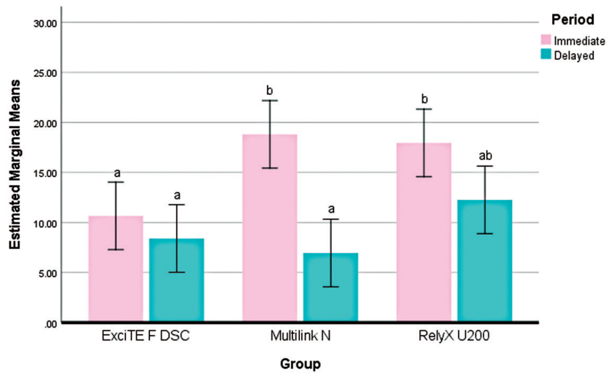

Figure 4: The bar graph of microtensile bond strength by groups (n=10/group). Same letter means no statistically significant difference and different letters means statistically significant difference among the experimental groups.

Table 1: Comparison of microtensile bond strength between different adhesives at different sealer application times.

Group (MPa)	Immediate	Delay
Multilink N	18.81±6.61	6.95±3.76
RelyX U200	17.95±4.13	12.26±6.34
ExciTE F DSC	10.66±4.07	8.39±1.60

Table 2: Effect sizes (Cohen's d) comparing microtensile bond strength between immediate and delayed groups for each adhesive.

Adhesive system	Multilink N	RelyX U200	ExciTE F DSC
Effect size	0.74	0.47	0.34

Table 3: effect sizes (Cohen's d) comparing microtensile bond strength between adhesives at immediate and delayed time points.

Adhesive Comparison	Immediate	Delay
Multilink N/RelyX U200	0.16	1.02
Multilink N/ExciTE F DSC	1.48	0.50
RelyX U200/ExciTE F DSC	1.78	0.84

Table 4: Percentages of failure modes among experimental groups.

Groups	Types of failure (%)	Adhesive	Cohesive in Biodentine	Cohesive in MultiCore Flow	Mixed failure
ExciTE F DSC	Immediate	20	30	10	40
	Delayed	10	40	0	50
Multilink N	Immediate	20	40	0	40
	Delayed	30	30	0	40
RelyX U200	Immediate	0	50	0	50
	Delayed	10	30	0	60

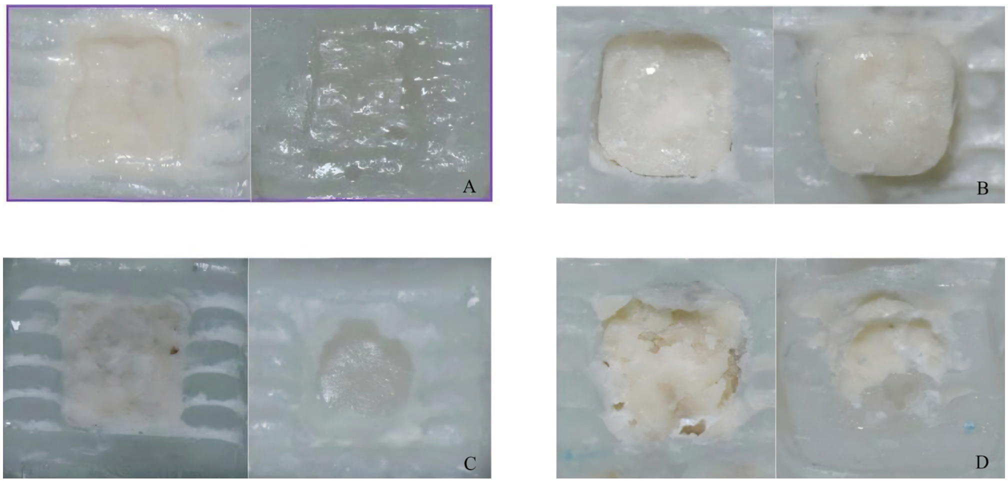

Figure 5: Representative images of the different failure modes observed after microtensile bond strength testing. (A), Adhesive failure at the Biodentine-MultiCore Flow interface: (B), Cohesive failure within the Biodentine material: (C), Cohesive failure within the MultiCore Flow material: (D), Mixed failure.

all experimental groups (Table 4). The different characteristics of failure modes observed are shown in Figure 5.

Discussion

Microtensile bond strength test is a widely used method to evaluate the bond strength between composite materials and dentin. It has also been applied to assess the bond strength between acrylic teeth and denture bases.(12) In this research, we modified the µTBS technique for a novel application in the field of endodontics, specifically focusing on bond strength between endodontic materials like Biodentine and MultiCore Flow with different adhesive systems. This model allows for a standardized and quantitative evaluation of bond strength used in endodontics. The results of this study will contribute to the development and optimization of bonding protocols for endodontic ceramic materials.

In this study, customized 3D-printed resin blocks were developed with a block and cover system aimed at reducing bias. However, further validation is required to confirm their efficacy and reproducibility. Despite the implementation of meticulous protocols, the potential for operational errors to impact on the findings cannot be eliminated. Moreover, µTBS testing may not fully represent clinical performance due to the complexities of the oral environment. Future investigations could benefit from exploring alternative methods, such as tensile tests, which are generally less sensitive and may provide more reliable results.

The observed differences in bond strength between adhesive systems can be attributed to their varying interaction mechanisms with Biodentine. This study found that the etch-and-rinse system, ExciTE F DSC, exhibited lower immediate bond strength, suggesting that acid-etching may not create optimal surface conditions for micro-retention on Biodentine's surface, potentially due to differences in its microstructure compared to dentin. The self-adhesive system (RelyX U200) demonstrated superior immediate bond strength compared to ExciTE F DSC, possibly due to the chemical interaction of its functional monomers with Biodentine's components. While Multilink N (self-etch) showed high initial bond strength, its significant decrease over time suggests potential hydrolytic degradation at the interface, a known concern with some self-etch adhesives. According to a study by Odabas *et al.,* in 2013[13] studies on various bonding systems for composite resin restorations to Biodentine at different time points have shown that etch-and-rinse systems exhibited a decrease in shear bond strength, which is consistent with this study. The ExciTE F DSC group, one of the etch-and-rinse systems, demonstrated the lowest shear bond strength compared to other groups in the immediate group. Our findings revealed that the self-adhesive system provided superior bond strength compared to etch-and-rinse adhesives system at all time points, particularly in the immediate bonding group. This is consistent with previous studies[14] although the delayed bonding group exhibited some variability. These findings suggest that the acid-etching process, typically known to induce surface porosity and thereby enhancing micro-retention and bond strength, may not facilitate comparable micro-retention in Biodentine, nor may it substantially improve bond strength between the two materials. Alternatively, it is possible that surface porosity from acid etching did not occur, or that the etching duration was either too brief or too prolonged. These results indicate that while the choice of bonding system can influence initial bond strength, other factors, such as clinical variables and material properties, may also contribute to the long-term performance of composite restorations bonded to Biodentine.

When comparing between different time point, The bar graph (Figure 4) shows that the immediate groups exhibited higher bond strength compared to the delayed groups in all experimental conditions. Our results are at odds with those reported by Odabas *et al.,*[13] which reported an increase in shear bond strength when bonding was delayed for 24 hours. They attributed this to the polymerization shrinkage of composite resins, which can induce tensile stresses on the unset Biodentine, leading to interfacial failure. However, our study used MultiCore Flow, a dual-cure material. Odabas *et al.*[15] used Clearfil Majesty (Kuraray Noritake Dental Inc., Okayama, Japan), a nanohybrid composite. While Clearfil Majesty is a high-quality material, studies have indicated it can generate relatively high polymerization stress. Multi Core Flow, in contrast, has been shown to exhibit a lower degree of conversion compared to some light-cured resins[16] and its polymerization stress has been reported as 10.9 MPa, within the range of many resin composites.[17] This lower polymerization stress likely reduces the tensile forces at the Biodentine-adhesive interface, potentially mitigating the negative impact of immediate bonding observed by Odabas *et al.*[13] Despite this, the long-term decrease in bond strength, especially with Multilink N, suggests that factors beyond initial shrinkage stress, such as hydrolytic degradation, significantly influence bond durability. Another possible explanation for the higher bond strength in the immediate groups compared to the delayed groups is the setting reaction between Biodentine and MultiCore Flow, which may have enhanced the interfacial bond. Further studies are warranted to investigate this hypothesis.

A key limitation of this study was the relatively small sample size (n=10) used for microtensile bond strength testing. This small sample size has several implications. First, it increases the risk of committing Type II errors (false negatives). Second, microtensile bond strength measurements are inherently susceptible to high variability, influenced by factors such as specimen geometry, adhesive application, and inherent material properties. A sample size of ten may be insufficient to adequately represent the full range of this variability, obscuring the true distribution of bond strengths. Furthermore, the limited sample size reduces the external validity of our findings. Finally, with a small sample, the results are more susceptible to being skewed by outlier values. Anomalous bond strengths, arising from premature failures during specimen preparation or inconsistencies during testing, can exert a disproportionately large influence on the overall statistical analysis. Furthermore, while the specific bond strength values obtained in this study may not be directly transferable to other commercially available materials, the relative performance of the tested groups could offer valuable insights for clinicians when selecting materials. While this *in vitro* study provides valuable insights into μTBS of endodontic materials, further research is essential to bridge the gap to clinical outcomes. Studies replicating the oral environment, including thermocycling to simulate temperature fluctuations, could offer a more accurate assessment of long-term bond stability. Additionally, investigating the chemical interactions between endodontic and restorative materials and potential changes within these materials during the setting time could offer a deeper understanding of the bonding mechanisms. Such knowledge could play a critical role in developing improved material formulations and enhancing their clinical performance.

Conclusions

The immediate placement of adhesives on Biodentine demonstrated superior microtensile bond strength than the delayed placement. The self-adhesive system consistently had strong bond strengths at both time intervals. It is suggested that immediate placement and use of self-adhesive system may enhance the bond strength between Biodentine and MultiCore Flow in clinical applications.

Conflicts of Interest

The authors declare no conflict of interest.

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Original Article

Utilization and Satisfaction with Three Languages of Dental Terminology E-book

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Abstract

Objectives: With the rising number of Chinese residents in Thailand and Chinese becoming a global language, compelling messages and communication in healthcare are crucial for accurate information and optimal treatment. This pilot study investigated Thai dentists' utilization and satisfaction with the developed electronic "Three Languages of Dental Terminology (TLDT)" book.

Methods: Three hundred and thirteen dentists who graduated from the College of Dental Medicine, Rangsit University, were invited to the online survey using Google Forms. Demographic data, translation tool usage data, initial TLDT experience, and objectives in using TLDT were explored. TLDT utilization and satisfaction were assessed. Fisher's exact test and Pearson's Chi-Square were utilized to analyze the data.

Results: Eighty-eight (28.1%) dentists responded to the questionnaire. Respondents met foreign patients monthly, with Chinese patients being the most common group. Most dentists lacked Chinese fluency and relied on translation tools (68.2% use Google Translate). Dentists primarily used TLDT to translate Thai to English (53.4%) and English to Thai (42.0%). Thai, English, and Chinese usage patterns aligned with TLDT's goals, indicating successful implementation ($p<0.05$). Regarding utilization, TLDT was significantly associated with all objectives ($p<0.05$) except for spelling accuracy ($p=0.06$). Most respondents reported high satisfaction scores related considerably to finding words, word pairings, and text accuracy ($p<0.05$). Postgraduate levels respectively correlated with increased TLDT content satisfaction ($p=0.02$).

Conclusions: The TLDT e-book demonstrates promise as a valuable resource for health-care personnel, improving dental terminology communication in English and Chinese and might optimize dental care and postgraduate dental education in Thailand.

Keywords: Chinese, dental terminology, electronic book, English, Thai

Introduction

China's economic boom has propelled Mandarin into the world's second-most-spoken language.[1] An incidence of Chinese migrants seeking opportunities occupies Thailand's major cities. Their diverse motivations, from business ventures and education to lifestyle choices, highlight a growing need for effective communication, both verbal and non-verbal, in various sectors, including healthcare services.[2]

In the field of Dentistry, when Thai dentists meet Chinese-speaking patients, language barriers pose significant challenges. Dental clinics frequently visited by Chinese patients often lack the multilingual interpreters that large hospitals commonly provide.[3] The medical and dental history taking, treatment plan explanation, patient safety, and satisfaction are essential components that need to be clearly addressed. Failure to communicate adequately may cause misinterpretation, place patient health at risk, restrict treatment options, and may lead to litigation.[4] Interpreters, while helpful, can be misinterpreted due to the lack of knowledge of dental terminology.[5,6]

Adding another layer of complexity is the vast and specialized vocabulary of dental terminology. Existing resources in Thailand, like the "Thai Dental Terminology" book and an online version of the Thai-English glossary, provide a foundation but lack Chinese translations.[7] Developing the book "Three Languages of Dental Terminology (TLDT)" by our authors was a groundbreaking trilingual electronic book offering Thai, English, and Chinese translations.[8] The Thai terms originate from the book mentioned above. At the same time, the Chinese equivalents come from the "English-Chinese Dictionary of Stomatology," a bilingual dictionary focusing specifically on dental and stomatology terminology.[9] With over 3703 entries covering diverse topics, the electronic TLDT surpasses most bilingual resources and allows convenient searching for dental terminology in any of the three languages. TLDT, in the form of an e-book, comprised the key importance points for digital books in terms of accessibility, convenience, searchability, instant delivery, and cost-effectiveness. This innovative tool bridges the language gap in dentistry, promoting better communication, both speaking and writing, and ultimately, might improve patient outcomes and satisfaction.

However, this e-book hasn't been publicly tested yet. Therefore, this research aimed to explore its utilization and user satisfaction among Thai dentists who graduated from a private dental school, screening the way for further development and optimization of this valuable resource for bridging language barriers in dentistry.

Materials and Methods

The Rangsit University Ethical Committee, by the Declaration of Helsinki, granted this Ethical approval of the cross-sectional pilot study with reference number RSU-ERB 2023-014. Respondents identified as all Thai dentists who graduated from the College of Dental Medicine, Rangsit University, between 2010 and 2021, were invited and recruited to participate in the study. They were contacted through two main channels: direct phone calls and invitations via the "RSU GRADUATE" LINE group announcement. The Dean of the College of Dental Medicine and the LINE Official Account Administrator permitted us to obtain all contact information.

All participating respondents received the exact formal instructions and informed consent to ensure consistency. Questionnaires were employed as the research's primary data collection method and were collected entirely through online links. These links, sent via QR code, included four components: (1) a consent form with a study explanation; (2) a QR code for the Bookcaze application (Figure 1) and TLDT e-book; and (3 and 4) questionnaires presented in both Thai and English versions (Figure 2) which the respondents could either selected according to the language preference. Google Forms facilitated these questionnaires, which ensured respondent anonymity and data confidentiality. The TLDT e-book was hosted on the Bookcaze company website, and participating respondents were granted free access to download the application and use this free e-book. After downloading the application and signing in, the respondents browsed either the TLDT e-book in the “Medical Science” menu bar category or a “Free” store, then a PDF file of the “Thai-English-Chinese dental terminology” e-book could be downloaded and read or search words needed.

Researchers developed the research questionnaire, reviewed by three experts, and underwent content validity.[10] An item objective congruence index of 0.8 demonstrated acceptable content validity.[11] Item response formats included checklists, dichotomous scales, 5-point Likert scales (1 = least, 2 = few, 3 = moderate, 4

= much, 5 = most), and open-ended options for additional comments. The self-administered questionnaire comprised five sections, covering: Part 1: Demographic data (8 items); Part 2: Translation tool usage data (9 items); Part 3: Initial TLDT experience (4 items) and objectives in using TLDT (6 items); Part 4: TLDT utilization assessment (4 aspects); Part 5: TLDT satisfaction assessment (content and usage, four items each).

Six objectives in using TLDT were explored: finding words in other languages, finding synonyms, finding words that often appear together, checking text and spelling accuracy, and accessing other word information.

Questions for TLDT utilization assessment included:

1. To what extent would you use TLDT if you treated Chinese-speaking patients?
2. How necessary is a read-aloud function in TLDT?
3. How necessary are illustrations in TLDT?
4. How necessary are sentence examples in TLDT?

TLDT satisfaction was assessed in two areas: content and usage.

Content satisfaction was evaluated in four aspects:

1. Finding the searched word(s): Did users successfully find the word they were looking for?
2. Accuracy of meaning: Did the dictionary provide the correct definition for the word?
3. Variety of word choices: Were users offered alternative words or synonyms?
4. Trilingual understanding: Could users simultaneously see the word in Thai, English, and Chinese?

Usage satisfaction was investigated in four areas:

1. Search speed: Could users find words quickly and easily?
2. Symbol clarity: Were the app's symbols understandable and intuitive?
3. Font readability: Was the font size and style easy to read on the screen?
4. Word saving: Could users save and retrieve frequently used words?

A sample size calculation (95% confidence interval (CI), 5% margin of error) established a requirement of 271 responses, accounting for an anticipated 40% response rate.(12) Data collection spanned July-October 2023. All data was entered and analyzed using IBM® SPSS® Statistics version 29.0.1.0. Descriptive statistics (frequency, percentage, and median) were employed after the normal distribution was tested, while Fisher's Exact Test and Pearson Chi-Square tests including odd ratio (OR) explored relationships between objectives, utilization, and satisfaction.

Figure 1: QR Code for the Bookcaze application and TLDT e-book.

Figure 2: QR Code for the questionnaires presented in both Thai and English versions.

Results

Three hundred and thirteen RSU graduates were invited to participate in the study, and 88 responded (28.1% response rate). All respondents were Thai, with a slight female majority (54 females, 61.4% vs. 34 males, 38.6%). The respondents' ages ranged from 25 to 40 years, averaging 29. Most (84.1%) used Thai and English, while 9.1% used Thai for patient communication. Only five respondents (5.7%) were fluent in all three languages (Thai, Chinese, and English), while one respondent (1.1%) was able to speak Thai, English, and Korean. Two-thirds (68.2%) were pursuing dental specializations in various fields, 17.0% were already specialists, and 14.8% were general dentists.

Regarding respondents' work locations, 67.0% worked in the capital city, Bangkok, 12.5% in surrounding areas (Pathum Thani, Samut Prakan, Nakhon Pathom, Nonthaburi), and 20.5% in other provinces. Most of these (71.6%) worked in one setting (either private clinic, hospital, or university), 25.0% in two, and 3.4% in three settings. Eighty-five (96.6%) respondents encountered foreign patients monthly, with only three (3.4%) seeing no foreign patients. Fifty-two respondents (59.1%) met 1-5 foreign patients, eighteen (20.5%) met 6-10, and fifteen (16.9%) met more than 10. Regarding patients' race, 58.0% met Chinese patients, while 42.0% did not. Of those who saw Chinese patients, 82.4% treated 1-5, 15.7% treated 6-10, and only 1.9% treated more than 10 Chinese patients monthly.

Nevertheless, most respondents (93.2%) could not speak Chinese, while only 6 (6.8%) could. Google Translate was the most popular tool for communication, and it was used by two-thirds of respondents (68.2%). The remaining apps used were ChatGPT, MediBabble, and an online dictionary. Three respondents (two in the hospitals and one in a clinic) relied on interpreters. Learning, education, academic writing, vocabulary searches, and novel reading were performed apart from communication from the mentioned apps. English was the primary language used, with translation needed only for occasional interactions with Chinese patients. Twenty-eight respondents (70.0%) were truly satisfied with the mentioned apps, 10 (25.0%) were moderately satisfied, and 2 (5.0%) were somewhat satisfied. Most respondents (83, or 94.3%) preferred smartphones for these translation apps, while the remaining 5 (5.7%) used tablets and computers.

After using the TLDT e-book, most respondents (47, or 53.4%) used it for Thai-to-English translation, followed by English-to-Thai by 37 (42.0%). Furthermore, the median assessment scores of utilization for TLDT were high (Likert scale 4) across all four questions. Overall, the median satisfaction score with the content and usage of TLDT was also high (Likert scale 4). Therefore, we stratified the data according to the median score into two groups (least to moderate versus much to most) for further analysis.

Table 1 shows the statistically significant pattern of TLDT usage related to six objectives in using TLDT, obtained for Thai-to-English (according to the objectives shown consecutively in Table 1, OR=8.5; 95% CI 3.1, 22.8 $p<0.001$; OR=10.8; 95% CI 4.0, 29.4 $p<0.001$; OR=8.8; 95% CI 3.3, 23.6 $p<0.001$; OR=10.2; 95% CI 3.8, 27.5 $p<0.001$; OR=9.1; 95% CI 3.4, 24.2 $p<0.001$; OR=5.7; 95% CI 2.2, 14.7 $p<0.001$, respectively), and English-to-Thai (OR=4.8; 95% CI 1.8, 13.0 $p<0.001$; OR=8.2; 95% CI 3.1, 21.7 $p<0.001$; OR=4.0; 95% CI 1.7, 9.9 $p<0.001$; OR=4.1; 95% CI 1.6, 10.4 $p<0.001$; OR=3.8; 95% CI 1.5, 9.6 $p=0.01$; OR=3.2; 95% CI 1.3, 7.8 $p=0.01$, respectively). A similar pattern was also demonstrated with Thai-to-English-to-Chinese translation across all objectives ($p<0.05$).

Considering the relationship of interested research data, Table 2 shows the respondents' demographic data with TLDT utilization or satisfaction. Age, gender, workplace province, and workplace type had no statistically significant relationship with TLDT utilization or satisfaction. The only exception was the educational level, postgraduate, related to content satisfaction with the TLDT (OR=6.2; 95% CI 1.4, 27.5; $p=0.02$).

Table 3 shows that TLDT utilization was statistically significant with all six objectives in using the TLDT except spelling accuracy (according to the objectives shown consecutively in Table 3, OR=3.7; 95% CI 1.3, 10.6 $p=0.02$; OR=4.6; 95% CI 1.4, 15.3 $p=0.01$; OR=4.1; 95% CI 1.2, 13.6 $p=0.02$; OR=5.3; 95% CI 1.7, 16.3 $p<0.001$; OR=5.5; 95% CI 1.5, 20.6 $p<0.001$, respectively). Interestingly, the content satisfaction levels were significantly related to three objectives: finding words in other languages (OR=6.7; 95% CI 1.3, 34.7; $p=0.03$), finding words that often appear together (OR=7.8; 95% CI 1.1, 36.3; $p=0.04$), and checking text accuracy (OR=5.4; 95% CI 1.1, 27.8; $p=0.04$). A similar pattern was also revealed for usage satisfaction (OR=3.2; 95% CI 1.1, 9.4; $p=0.03$; OR=9.5; 95% CI 2.0, 44.5; $p<0.001$; and OR=3.4; 95% CI 1.1, 10.1; $p=0.03$, respectively).

Regarding unfound words in TLDT, 13 respondents (14.8%) reported encountering some (29 unfound words). Eight words were present in TLDT but were not found with the respondents' search terms. The remaining 21 unfound words were absent as well.

Discussion

This pilot cross-sectional study used an online questionnaire to investigate 88 Thai dentists' utilization and satisfaction with a Thai-English-Chinese dental terminology e-book. The results showed that the developed TLDT e-book is valuable for dentists and postgraduate dental students in Thailand. The e-book is easy to use and con-

Table 1: Relationship between the pattern of TLDT usage and objectives in using the TLDT.

		Find words in other languages		*p**	Synonym/Similar words		*p**	Words that often appear together		*p**	Accuracy of text		*p**	Accuracy of spelling		*p**	Other information about the word		*p**
		Least to moderate (n=34)	Much to most (n=54)		Least to moderate (n=46)	Much to most (n=42)		Least to moderate (n=48)	Much to most (n=40)		Least to moderate (n=38)	Much to most (n=50)		Least to moderate (n=37)	Much to most (n=51)		Least to moderate (n=50)	Much to most (n=38)	
Translate Thai to English	Least to moderate	26 (76.5%)	15 (27.8%)	0.00	33 (71.7%)	8 (19.0%)	0.00	33 (68.8%)	8 (20.0%)	0.00	29 (76.3%)	12 (24.0%)	0.00	28 (75.7%)	13 (25.5%)	0.00	32 (64.0%)	9 (23.7%)	0.00
	Much to most	8 (23.5%)	39 (72.2%)		13 (28.3%)	34 (81.0%)		15 (31.2%)	32 (80.0%)		9 (23.7%)	38 (76.0%)		9 (24.3%)	38 (74.5%)		18 (36.0%)	29 (76.3%)	
Translate Thai to Chinese	Least to moderate	28 (82.4%)	33 (61.1%)	0.06	34 (73.9%)	27 (64.3%)	0.36	36 (75.0%)	25 (62.5%)	0.25	29 (76.3%)	32 (64.0%)	0.25	27 (73.0%)	34 (66.7%)	0.64	40 (80.0%)	21 (55.3%)	0.02
	Much to most	6 (17.6%)	21 (38.9%)		12 (26.1%)	15 (35.7%)		12 (25.0%)	15 (37.5%)		9 (23.7%)	18 (36.0%)		10 (27.0%)	17 (33.3%)		10 (20.0%)	17 (44.7%)	
Translate Chinese to English	Least to moderate	31 (91.2%)	44 (81.5%)	0.36	42 (91.3%)	33 (78.6%)	0.13	43 (89.6%)	32 (80.0%)	0.24	35 (92.1%)	40 (80.0%)	0.14	34 (91.9%)	41 (80.4%)	0.22	46 (92.0%)	29 (76.3%)	0.07
	Much to most	3 (8.8%)	10 (18.5%)		4 (8.7%)	9 (21.4%)		5 (10.4%)	8 (20.0%)		3 (7.9%)	10 (20.0%)		3 (8.1%)	10 (19.6%)		4 (8.0%)	9 (23.7%)	
Translate Chinese to Thai	Least to moderate	29 (85.3%)	38 (70.4%)	0.13	37 (80.4%)	30 (71.4%)	0.45	39 (81.2%)	28 (70.0%)	0.32	31 (81.6%)	36 (72.0%)	0.33	29 (78.4%)	38 (74.5%)	0.80	44 (88.0%)	23 (60.5%)	0.01
	Much to most	5 (14.7%)	16 (29.6%)		9 (19.6%)	12 (28.6%)		9 (18.8%)	12 (30.0%)		7 (18.4%)	14 (28.0%)		8 (21.6)	13 (25.5%)		6 (12.0%)	15 (39.5%)	
Translate English to Thai	Least to moderate	27 (79.4%)	24 (44.4%)	0.00	37 (80.4%)	14 (33.3%)	0.00	35 (72.9%)	16 (40.0%)	0.00	29 (76.3%)	22 (44.0%)	0.00	28 (75.7%)	23 (45.1%)	0.01	35 (70.0%)	16 (42.1%)	0.01
	Much to most	7 (20.6%)	30 (55.6%)		9 (19.6%)	28 (66.7%)		13 (27.1%)	24 (60.0%)		9 (23.7%)	28 (56.0%)		9 (24.3%)	28 (54.9%)		15 (30.0%)	22 (57.9%)	
Translate English to Chinese	Least to moderate	27 (79.4%)	41 (75.9%)	0.80	35 (76.1%)	33 (78.6%)	0.81	36 (75.0%)	32 (80.0%)	0.62	31 (81.6%)	37 (74.0%)	0.45	30 (81.1%)	38 (74.5%)	0.61	39 (78.0%)	29 (76.3%)	1.00
	Much to most	7 (20.6%)	13 (24.1%)		11 (23.9%)	9 (21.4%)		12 (25.0%)	8 (20.0%)		7 (18.4%)	13 (26.0%)		7 (18.9%)	13 (25.5%)		11 (22.0%)	9 (23.7%)	
Translate Thai to English to Chinese	Least to moderate	34 (100.0%)	41 (75.9%)	0.00	45 (97.8%)	30 (71.4%)	0.00	45 (93.8%)	30 (75.0%)	0.02	37 (97.4%)	38 (76.0%)	0.01	36 (97.3%)	39 (76.5%)	0.01	48 (96.0%)	27 (71.1%)	0.00
	Much to most	0 (0.0%)	13 (24.1%)		1 (2.2%)	12 (28.6%)		3 (6.2%)	10 (25.0%)		1 (2.6%)	12 (24.0%)		1 (2.7%)	12 (23.5%)		2 (4.0%)	11 (28.9%)	

*Fisher's Exact Test/Pearson Chi-Square tests

Table 2: Relationship between demographic data of the respondents and utilization and satisfaction of TLDT

Variables	Utilization (N=88)			*p**	Satisfaction of content (N=88)			*p**	Satisfaction of usage (N=88)			*p**
	Least (n=3)	Moderate (n=16)	Most (n=69)		Least (n=0)	Moderate (n=9)	Most (n=79)		Least (n=3)	Moderate (n=16)	Most (n=70)	
Age (years)												
< 29	1 (33.3%)	7 (43.8%)	31 (44.9%)	0.92	0 (0%)	3 (33.3%)	36 (45.6%)	0.48	1 (50.0%)	6 (37.5%)	32 (45.7%)	0.83
≥ 29	2(66.7%)	9 (56.2%)	38 (55.1%)		0 (0%)	6 (66.7%)	43 (54.4%)		1 (50.0%)	10 (62.5%)	38 (54.3%)	
Sex												
Male	3 (100.0%)	5 (31.2%)	26 (37.7%)	0.08	0 (0.0%)	3 (33.3%)	31 (39.2%)	1.00	1 (50.0%)	3 (18.7%)	30 (42.9%)	0.19
Female	0 (0.0%)	11 (68.8%)	43 (62.3%)		0 (0.0%)	6 (66.7%)	48 (60.8%)		1 (50.0%)	13 (81.3%)	40 (57.1%)	
Education												
General dentist	2 (66.7%)	1 (6.2%)	10 (14.5%)	0.09	0 (0.0%)	4 (44.4%)	9 (11.4%)	0.02	0 (0.0%)	3 (18.7%)	10 (14.3%)	0.27
Further study	1 (33.3%)	11 (68.8%)	48 (69.6%)		0 (0.0%)	5 (55.6%)	55 (69.6%)		2 (100.0%)	13 (81.3%)	45 (64.3%)	
Specialist	0 (0.0%)	4 (25.0%)	11 (15.9%)		0 (0.0%)	0 (0.0%)	15 (19.0%)		0 (0.0%)	0 (0.0%)	15 (21.4%)	
Province of workplaces												
Bangkok	2 (66.7%)	9 (56.2%)	48 (69.6%)	0.70	0 (0.0%)	5 (55.6%)	54 (68.4%)	0.62	1 (50.0%)	8 (50.0%)	50 (71.4%)	0.27
Perimeter	0 (0.0%)	2 (12.5%)	9 (13.0%)		0 (0.0%)	2 (22.2%)	9 (11.4%)		0 (0.0%)	2 (12.5%)	9 (12.9%)	
Other provinces	1 (33.3%)	5 (31.3%)	12 (17.4%)		0 (0.0%)	2 (22.2%)	16 (20.2%)		1 (50.0%)	6 (37.5%)	11 (15.7%)	
Workplaces												
Private Clnic	1 (33.3%)	9 (56.2%)	48 (69.6%)	0.47	0 (0.0%)	4 (44.4%)	54 (68.3%)	0.08	1 (50.0%)	9 (56.3%)	48 (68.6%)	0.73
Hospital	1 (33.3%)	4 (25.0%)	15 (21.7%)		0 (0.0%)	2 (22.2%)	18 (22.8%)		1 (50.0%)	5 (31.2%)	14 (20.0%)	
Private Clinic and University	1 (33.3%)	3 (18.8%)	6 (8.7%)		0 (0.0%)	3 (33.3%)	7 (8.9%)		0 (0.0%)	2 (12.5%)	8 (11.4%)	

*Fisher's Exact Test/Pearson Chi-Square tests

Table 3: Relationship between objectives in using TLDT and utilization and satisfaction with TLDT

The objective for using TLDT		Utilization (N=88)		p*	Satisfaction of content (N=88)		p*	Satisfaction of usage (N=88)		p*
		Least to moderate (n=19)	Much to most (n=69)		Least to moderate (n=9)	Much to most (n=79)		Least to moderate (n=18)	Much to most (n=70)	
Find words in other languages	Least to moderate	12 (63.2%)	22 (31.9%)	0.02	7 (77.8%)	27 (34.2%)	0.03	11 (61.1%)	23 (32.9%)	0.03
	Much to most	7 (36.8%)	47 (68.1%)		2 (22.2%)	52 (65.8%)		7 (38.9%)	47 (67.1%)	
Synonym/Similar words	Least to moderate	15 (78.9%)	31 (44.9%)	0.01	7 (77.8%)	39 (49.4%)	0.16	13 (72.2%)	33 (47.1%)	0.68
	Much to most	4 (21.1%)	38 (55.1%)		2 (22.2%)	40 (50.6%)		5 (27.8%)	37 (52.9%)	
Words that often appear together	Least to moderate	15 (78.9%)	33 (47.8%)	0.02	8 (88.9%)	40 (50.6%)	0.04	16 (88.9%)	32 (45.7%)	0.00
	Much to most	4 (21.1%)	36 (52.2%)		1 (11.1%)	39 (49.4%)		2 (11.1%)	38 (54.3%)	
Accuracy of text	Least to moderate	14 (73.7%)	24 (34.8%)	0.00	7 (77.8%)	31 (39.2%)	0.04	12 (66.7%)	26 (37.1%)	0.03
	Much to most	5 (26.3%)	45 (65.2%)		2 (22.2%)	48 (60.8%)		6 (33.3%)	44 (62.9%)	
Accuracy of spelling	Least to moderate	12 (63.2%)	25 (36.2%)	0.06	6 (66.7%)	31 (39.2%)	0.16	10 (55.6%)	27 (38.6%)	0.28
	Much to most	7 (36.8%)	44 (63.8%)		3 (33.3%)	48 (60.8%)		8 (44.4%)	43 (61.4%)	
Other information about the word	Least to moderate	16 (84.2%)	34 (49.3%)	0.00	8 (88.9%)	42 (53.2%)	0.07	14 (77.8%)	36 (51.4%)	0.06
	Much to most	3 (15.8%)	35 (50.7%)		1 (11.1%)	37 (46.8%)		4 (22.2%)	34 (48.6%)	

*Fisher's Exact Test/Pearson Chi-Square tests

tains a comprehensive list of Thai, English, and Chinese dental terminologies. Dentists and postgraduate dental students are satisfied with the TLDT e-book and believe it helps improve communication with foreign patients or writing for academic purposes.

Because of different types of communication, such as written, verbal, or non-verbal communication[13], using TLDT via verbal communication was not prominent in this study. Although most respondents encountered foreign patients monthly, with Chinese patients being the most common, most dentists cannot speak Chinese. English was the primary language used for occasional interactions with Chinese patients. Google Translate is the most popular translation tool, similar to the previous studies.[14,15] Even though the number of dentists using Chinese translation was relatively small, from our results, the pattern of dentist usage from Thai to English, English to Thai, and Thai to English to Chinese revealed a significant relationship to the six objectives of TLDT. This study, therefore, highlights the need for trilingual translation tools for dental terminology.[16,17]

Notably, an interesting finding emerged. Dentists pursuing specialization showed a statistically significant link with higher content satisfaction. Those used them for communication, learning, and academic writing, similar to the published data.[18] Dentists in postgraduate programs are likelier to write educational documents, leading to greater TLDT utilization and satisfaction. This result aligns with previous researches suggesting specialists seek educational resources like e-books for their specialized terminology and complex information needs.[19-21]

Usage patterns involving Thai-English, English-Thai, and Thai-English-Chinese translations were significantly associated with all six TLDT objectives. This result suggests that common usage aligns closely with the e-book's intended purpose. This pattern strongly correlated with key objectives like finding words in other languages, identifying synonyms, and checking text accuracy. Therefore, the e-book primarily serves as a cross-language dental terminology lookup tool between Thai and English.

This study also explored the relationship between TLDT objectives, utilization, and user satisfaction. While utilization was significantly linked to five out of six objectives (excluding spelling accuracy), user satisfaction only correlated with finding words in other languages, identifying words that often appear together, and text accuracy. This suggests that the equivalent finding of the core aim of cross-language terminology lookup and proper word usage primarily drive satisfaction.[18] Additionally, the closer match between utilization and objectives than satisfaction and objectives suggests that respondents used the TLDT effectively for its intended purpose.

Limitations of this preliminary study include a relatively small sample size and a low response rate (28.12%) compared to the expected 40%.[12] This could be due to recent concerns about phone scams in Thailand[22] and difficulty reaching respondents with outdated contact information. Future research could include interpreters or wider dental professional clinicians and utilize diverse contact methods to improve participation and generalizability of the study. Administrations of the questionnaire to calculate test-retest reliability should be performed to strengthen the findings. A few respondents reported encountering unfound words in the TLDT e-book, suggesting potential areas for improvement. The TLDT itself includes incomplete three-language coverage, leading to missing search terms. Additionally, respondents suggested improvements like adding pronunciation, pictures, vocabulary usage examples, translation explanations, and categorizing word lists based on dental departments or difficulty. Further development and public testing are needed to refine and optimize these tools for maximum impact.

Conclusions

This study suggests that multilingual e-books like TLDT can significantly improve the accessibility of dental terminology in Thai, English, and Chinese. The TLDT e-book is a helpful tool for enhancing communication of dental terminologies between Thai, English, and Chinese in Thailand. The e-book is easy to use and contains a comprehensive list of Thai, English, and Chinese dental terminologies. Dentists and dental students who participated in the study reported that they are satisfied with the TLDT e-book and believe it helps improve communication with foreign patients and the writing of academic papers.

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Conflicts of Interest

The authors declare no conflict of interest.

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OSR ORAL SCIENCES REPORTS

Original Article

The Effect of Different Surface Treatments of Shear Bond Strength of Repaired Polymer-infiltrated Ceramic Network Materials

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Abstract

Objectives: This study aimed to determine the alternative surface treatment method for repairing aged polymer-infiltrated ceramic network materials (PICNs) utilizing a shear bond strength (SBS) test.

Methods: A PICNs block (VITA Enamic®) was cut into 5x5x5 mm^3 followed by thermo-cycling for 10,000 cycles. The specimens were then randomly divided into four groups (n=12), based on different surface treatments. Group HF+Si: treated with a 9.5% hydro-fluoric acid and silane application, Group HF+Si+He: treated with a 9.5% hydrofluoric acid and silane application followed by an application of a hydrophobic resin monomer, Group MEP: treated with a self-etching ceramic primer, Group MEP+He: treated with a self-etching ceramic primer followed by an application of a hydrophobic resin monomer. All specimens were repaired with a resin composite and underwent a thermocycling aging process for 10,000 cycles before measuring shear bond strength.

Results: One-way ANOVA revealed a significant difference in SBS among all groups. Group MEP exhibited a significantly lowest mean SBS value ($p<0.05$), while, mean SBS values from groups HF+Si, HF+Si+He, and MEP+He did not show statistically significant differences.

Conclusions: Treating aged PICNs with only self-etching ceramic primer group provided an insufficient shear bond strength. However, when a hydrophobic resin monomer was applied after conditioning with self-etching ceramic primer, shear bond strength was distinctly improved to a comparable level to those treated with 9.5% hydrofluoric acid and silane primer.

Keywords: hydrofluoric acid, hyphobic resin monomer, self-etching ceramic primer, silane, PICNs

Introduction

Advanced developments in digital technology and manufacturing processes have resulted in a dramatic paradigm shift in dentistry and the widespread use of computer-aided design/computer-aided manufacturing (CAD/CAM) in the fabrication of indirect dental restorations.[1,2] While various dental ceramics are currently improved and available for CAD/CAM fabrication[2,3], they are still brittle and susceptible to cracks and fractures. Such fractures are difficult to repair[4-6], impairing restoration longevity. As a result, the trend of development aims to reduce risk of fracture in indirect posterior restorations.[5]

Since 2013, the only one commercially available polymer-infiltrated ceramic materials (PICNs) with CAD/CAM technology, VITA Enamic® (VITA Zahnfabrik, Bad Säckingen, Germany), has been introduced to dental profession. VITA Enamic® is composed of a network of feldspathic ceramics infiltrated by a polymeric phase.[4,7-9] The polymer-infiltrated ceramic materials exhibited lower brittleness, rigidity, and hardness than glass ceramics. They also demonstrated increased flexibility and fracture toughness.[7,9] This may result in an improvement in stress distribution, particularly during the mastication process.[10] Nevertheless, several factors, including high masticatory forces, parafunctional habits, and internal defects within the material, critically impact the success of dental restorations in a long period of clinical service. Crack propagation induced by these factors may lead to fracture of restoration, significantly compromising longevity.[7-9] According to a three-year clinical research study conducted by Spitznagel *et al.*,[11] they discovered that fractures were the primary cause of failures in 103 PICNs CAD/CAM restorations which were unacceptable bulk fractures and chipping. The repairable failed restorations were repaired with resin composite and showed no failure up to three-year follow up.[11] Among those chipping, non-catastrophic fractures were repairable, extending esthetics and functional preservation of restorations.[12,13]

Previous studies have been reported that the most effective technique for repairing polymer-infiltrated ceramic materials was etching with hydrofluoric acid followed by silane application[14, 15] and re-restoring with resin composite.[13] However, hydrofluoric acid was considered a hazardous substance, especially when it was spilled on tissues. The aggressiveness of this acid can cause burns that frequently result in deep tissue necrosis.[13,16] The alternative less aggressive acid has been developed in order to reduce such complication during repairing procedure. A new self-etching glass-ceramic primer (Monobond Etch & Prime; Ivoclar Vivadent, Schaan, Liechtenstein) consists of four distinct compositions including an ammonium polyfluoride, phosphoric acid ester, solvent and silane enclosing in one bottle.[17] Murillo *et al.,*[18] compared the effects of the new self-etching primer with the contemporary technique on bonding to glass-ceramic and resin cement. The result indicated no statistically significant difference in microtensile bond strength between the two groups. However, no study has examined the effectiveness of either self-etching primer alone or combined with a hydrophobic resin on the repair of polymer-infiltrated ceramic network materials.

The application of bonding agents on old ceramic before repairing with resin composite has also been discussed.[19,20] According to certain studies, using bonding agents, ones containing hydrophobic resin monomer, improved the bond between glass ceramics and resin composites.[19,20] On the other hand, the systematic review and meta-analysis performed by Nogueira *et al.,*[21] showed insufficient evidence to encourage using an adhesive system as an adjunctive surface treatment before repairing. With this inconsistency, the study about the benefit of a hydrophobic resin application on repairing polymer-infiltrated ceramic network materials surface, especially when combined with self-etch ceramic primer is scarce.

Altogether, these raised the question whether the new self-etching ceramic primer combined with a hydrophobic resin monomer could effectively repair the polymer-infiltrated ceramic network materials (PICNs). Therefore, the purpose of this study was to determine the different surface treatment methods for repairing polymer-infiltrated ceramic network material (PICNs) using shear bond strength. Additionally, an application of a hydrophobic resin monomer before placement of resin composites was also investigated in the present study.

Materials and Methods

Specimen preparation

A total of 6 CAD-CAM PICNs block (VITA Enamic®, VITA Zahnfabrik, Bad Säckingen, Germany), size 12×14×18 mm^3, were cut into 5x5x5 mm^3 slices using a low-speed diamond cutting (Isomet Low Speed Saw, Buehler, USA) under constantly running water followed by a thermocycling aging process was simulated using dwelling in water between temperatures of 5-55ºC for 10,000 cycles with a 60 s dwell time per bath (THE1400, SD Mechatronik GmbH). All specimens were then embedded in a self-curing acrylic resin. Each block was polished with five-step silicon carbide abrasive papers (200, 400, 600, 800, and 1,000 grit) using a polishing machine (NANO 2000, Pace Technologies, USA) to achieve standardized smooth surfaces before being cleaned with water for 5 minutes in an ultrasonic cleaner (Bransonic, Germany). All processes of specimen preparation are shown in Figure 1.

Surface treatment

The details of the material used in the study are shown in Table 1, and the experimental procedures are displayed in Figure 1. The specimens were randomly divided into four groups according to the surface treatment (n=12).

Group1 (HF+Si): etch with 20-µl of 9.5% hydrofluoric acid (PORCELAIN ETCHANT, Bisco, Schaumburg, USA) for 60 seconds, wash with air-water spray for 60 seconds, and air-dry for 10 seconds. Afterward, apply a 10-µl Silane Primer (Kerr, Brea, USA) in one direction with a 1.5-mm microbrush (Cotisen®, Huanghua promise dental, Hebei, China), wait 60 seconds, and drying with warm air from a 10-cm distance for 20 seconds. The warm air was calibrated to 60°C using a thermometer (Testo Saveris 2-T3, Testo SE & Co., Germany).

Group 2 (HF+Si+He): same as group 1, additionally, apply a 10-µl Heliobond (Ivoclar Vivadent, Schaan, Liechtenstein) in one direction with a 1.5-mm microbrush (Cotisen®, Huanghua promise dental, Hebei, China) and photopolymerized (Demi™Plus, Kerr, Orange, CA, USA) for 20 seconds

Group 3 (MEP): applying 20-µl Monobond Etch & Prime (Ivoclar Vivadent, Schaan, Liechtenstein) using a 1.5-mm microbrush (Cotisen®, Huanghua promise dental, Hebei, China), agitate on the surface for 20 seconds, and wait for 40 seconds. Then, thoroughly rinse off with water for 20 seconds and drying the specimen with warm air with the same calibration as used in group 1.

Group4 (MEP+He): same as group 3, additionally, apply a 10-µl Heliobond (Ivoclar Vivadent, Schaan, Liechtenstein) in one direction with a 1.5-mm microbrush (Cotisen®, Huanghua promise dental, Hebei, China) and photopolymerized (Demi™Plus, Kerr, Orange, CA, USA) for 20 seconds

Repair method

A clear silicone mold with 3x3 mm^2 (wide x height) was placed at the center of each specimen to standardize the bonding area. Resin composite (Filtek™ Z350 XT, 3M ESPE, St. Paul, USA) with thickness of 1.5 mm. was applied in the mold and photopolymerized. The another increment with same thickness was then applied to provide 3 mm thickness of resin composite restoration. A light-polymerizing unit (Demi™Plus, Kerr, Orange, CA, USA), with a diameter size of 8 mm, was used to photopolymerize each increment for 40 seconds, the tip of the unit was touched to the mold at an intensity of 1,100 mW/cm^2, the device was calibrated with a radiometer (Optilux Radiometer, Kerr, Orange, CA, USA). After the polymerization, the silicone mold was carefully detached using a scalpel, and excess resin composite material was also gently removed. The specimens were then kept in

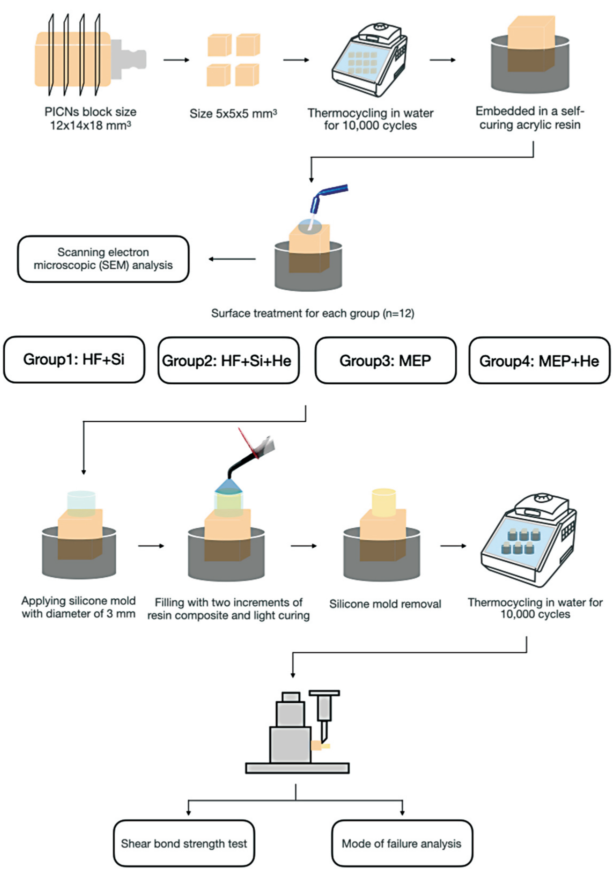

Figure 1: Flow chart of the experimental procedures.

Table 1: Material compositions.

Material	Type	Composition	Lot No.
VITA Enamic® (VITA Zahnfabrik, Bad Säckingen, Germany)	Polymer-infiltrated ceramic network materials (PICNs)	Ceramic content (86% wt, 75% vol): SiO_2 (58-63%), Al_2O_3 (20-23%), Na_2O (9-11%), K_2O (4-6%), B_2O_3 (0.5-2%), ZrO_2<1%, CaO<1% Polymer content (14% wt, 25% vol): UDMA, TEGDMA	99280
Filtek™ Z350 XT (3M ESPE, St. Paul, USA)	Nanofill resin composite	Filler: silica filler, non-agglomerated/non-aggregated 4 to 11 nm zirconia filler, and aggregated zirconia/silica cluster filler. Resin: Bis-GMA, UDMA, TEGDMA, Bis-EMA, PEGDMA	9783163
PORCELAIN ETCHANT (Bisco, Schaumburg, USA)	Hydrofluoric acid	9.5% Buffered hydrofluoric acid gel	2300001967
Monobond Etch & Prime (Ivoclar Vivadent, Schaan, Liechtenstein)	Self-etching ceramic primer	Butanol, tetrabutylammonium dihydrogen trifluoride, methacrylate phosphoric acid ester, bis(triethoxysilyl) ethane, silane methacrylate, colourant, ethanol, water	Z03CD9
Silane Primer (Kerr, Brea, USA)	Silane coupling agent	Ethanol, (1-methylethylidene)bis[4,1-phenyleneoxy(2- hydroxy-3,1-propanediyl)] bismethacrylate, Poly(oxy-1,2-ethanediyl), α,α'-[(1- methylethylidene)di-4,1-phenylene] bis[ω-[(2- methyl-1-oxo-2-propen-1-yl)oxy]-, 2,2'-ethylenedioxydiethyl dimethacrylate 3-trimethoxysilylpropyl methacrylate	9730905
Heliobond (Ivoclar Vivadent, Schaan, Liechtenstein)	Light-curing, single-component hydrophobic resin monomer	Bis-GMA, TEGDMA, photoinitiator	Z02TZ2

distilled water at 37°C for 24 hours before thermocycling in water between 5 and 55°C for 10,000 cycles with a 60-s dwell time per bath (THE1400, SD Mechatronik GmbH).

Shear bond strength test

After thermocycling, shear bond strength test was conducted using a universal testing machine (EZ-S500N, SHIMADZU, JAPAN). Each specimen was attached to a metal mold. And was loaded with a crosshead speed of 1 mm per minute and applied at the bonding interface until failure. The bond strength was recorded and calculated by Trapezium 2 program. The mean and standard deviation of shear bond strength in each group were analyzed.

Mode of failure analysis

Fractured specimens were examined under a stereomicroscope (SZ 61, OLYMPUS, JAPAN) to evaluate the failure mode at a magnification of 15X. Modes of failure were classified into 4 types as following: adhesive, cohesive in either the PICNs or resin composite, and mixed failure. The percentage of each mode was calculated based on the total specimens of each group.

Scanning electron microscopic (SEM) analysis

The two representative specimens were subjected to SEM analysis to evaluate topographic change after surface treatment by rinsing with deionized water, drying with oil-free air, sputter coating with a conductive 6-nm gold layer, and analyzing the surface structure with an SEM (JSM-6610LV Scanning Electron Microscope JEOL, USA) at an acceleration voltage 20 kV. Moreover, the two specimens of each group were selected after the shear bond strength test to display the failure surface.

Statistical analysis

Statistical analysis was performed using SPSS software (IBM SPSS statistics version 29.0.1.0, IBM; Armonk, NY, USA). All data was analyzed with a Shapiro-Wilk to test the normality of data distribution. The One-way ANOVA was used to compare the effect of surface treatment between groups in which the level of confident at 95% was considered to be statistically significant.

Result

Shear bond strength (SBS) and failure mode analysis

SBS values were normally distributed. Mean SBS values and standard deviations each group are shown in Table 2. One-way ANOVA demonstrated a statistically significant difference (p<0.05) of mean SBS values among all groups. Group 3 showed the lowest mean SBS values comparing to others. However, groups 1, 2, and 4 did no statistical difference.

The percentage of mode of failure is presented in Figure 2. Adhesive failure was the predominant mode observed exclusively in Group 3. In contrast, Groups 1, 2, and 4 primarily exhibited a mixed mode, although adhesive failure was also presented.

Scanning electron microscopic (SEM) analysis

Representative images of surface topography after each experimental protocol using SEM analysis are displayed in Figures 3. Abundant microporosity between the intact interpolymer network was observed in Group 1 (Figure 3B). Whereas slight surface roughness was observed in Group 3 (Figure 3D) which was similar to thermocyled PICNs surface (Figure 3A). However, a flat and smooth surface was found in either Group 2 (Figure 3C) or Group 4 (Figure 3E). Additionally, surface morphology of representative fracture surfaces was investigated and are presented in Figures 4. Fracture surface at adhesive interface was seen in adhesive failure mode (Figure 4A). For mixed mode of failure, partial fracture of either PICNs or resin composite could be seen as shown in Figure 4B and Figure 4C respectively.

Discussion

During the repair process, surface conditioning of the repaired substrate is the most critical factor determining success. Moreover, different surface conditioning methods can induce distinct topographic changes in various ceramic materials, leading to variations in bond strength.(22) The present study investigated different surface treatment protocols for repairing aged PICNs using shear bond strength test. The result showed that aged PICNs with different surface treatments exhibited different bond performances. The primary finding of the study was that the repairing PICNs with a self-etching ceramic primer alone was insufficient compared to conventional techniques, whereas the additional step of application of hydrophobic resin provided the effective surface treatment before repairing aged PICNs.

In line with the present study, previous research demonstrated that hydrofluoric acid treatment followed by the application of a silane coupling agent was the most effective method for surface treatment of the PICNs, including aged PICNs.(14,15) Eighty percent of PICNs consists of a feldspathic network, which is acid-labile. Hydrofluoric acid partially dissolves the glass-ceramic network, creating a distinct "honeycomb" pattern on material surface, as observed in the SEM image (Figure 3B).(12,23,24) When pre-hydrolyzed silane is applied, its inorganic component reacts with silicon dioxide on the etched glass surface forming siloxane bonds, while the methoxy groups bond with methacrylate-based resins. This silane-treated porosity allows micromechanical interlocking when resin cement is polymerized, resulting in a strong bond (Group HF+Si).(25-27)

Meanwhile, twenty percent of PICNs consists of a patented high-temperature and high-pressure polymerized resin, which resulted in a high degree of conversion of polymer-infiltration.(28) This property may reduce the potential for chemical copolymerization between free

Table 2: Means ± SD of the shear bond strength values (MPa) in each group.

Surface treatment (n=12)	Group 1 (HF+Si)	Group 2 (HF+Si+He)	Group 3 (MEP)	Group 4 (MEP+He)
Shear bond strength (MPa)	21.44±3.58^{A}	21.48±1.64^{A}	10.28±1.87^{B}	19.60±2.12^{A}

Means ± SD in MPa. Different capital letters in each row mean significantly different at p<0.05.
HF: Hydrofluoric acid; Si: Silane primer; He: Heliobond; MEP: Monobond Etch & Prime

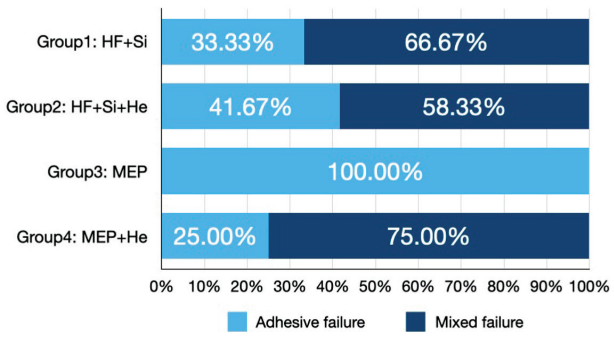

Figure 2: Mode of failure in each group.

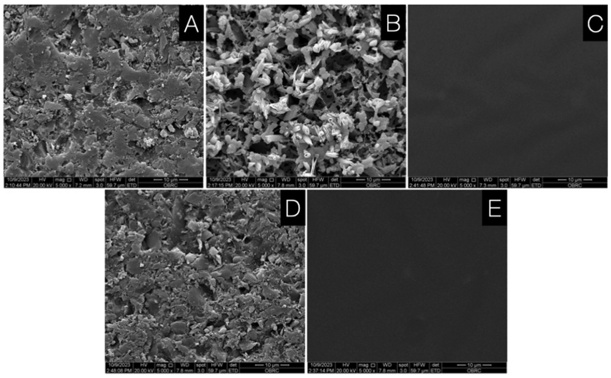

Figure 3: Representative SEM images after surface treatment at 5000X magnification. (A), Surface of aged PICNs presented roughness and narrow valley: (B), Aged PICNs, treated with 9.5% hydrofluoric acid and silane, exhibited numerous microporosities between the intact polymer phase: (C), Aged PICNs, treated with 9.5% hydrofluoric acid and silane followed by resin monomer application, revealed a flat and smooth surface: (D), Aged PICNs, treated with a self-etching ceramic primer, displayed slight surface roughness: (E), Aged PICNs treated with a self-etching ceramic primer followed by resin monomer application showed a smooth surface.

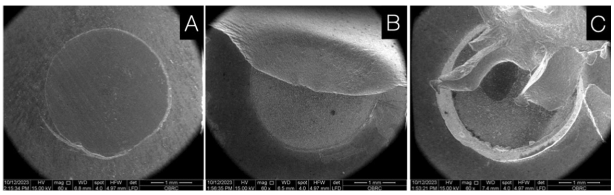

Figure 4: Representative SEM images of specimens after the shear bond strength test reveal different failure modes. (A), Adhesive failure, all the failure occurred only at the materials interface: (B), Mixed failure, partial fracture of the interface was shown and involved in PICNs: (C), Mixed failure, partial fracture at the interface was shown and involved in resin composite.

monomer in the PICNs and the resin-based materials. Additionally, this phase is resistant to hydrofluoric acid as it remained intact shown in Figure 3B, forming etching pattern that effectively facilitate bonding. Therefore, this micromechanical interlocking can be concluded that it has an even greater influence on the adhesive interface's performance compared to chemical reaction.[26]

The creation of sufficient space following glassy dissolution is essential for enhancing surface wettability and ensuring secure micromechanical interlocking between PICNs and resin-based materials. Unlike the HF+Si group, the porosities on PICNs treated with a self-etching ceramic primer (Group MEP) presented minimal surface modification, resembling the untreated surface as seen in Figure 3A and 3D. The main active ingredient in a self-etching ceramic primer responsible for glass-ceramic dissolution is Tetrabutylammonium dihydrogen trifluoride (TADF), which has lower acidic aggressiveness compared to hydrofluoric acid. Due to this milder etching effect, the removal of the glassy phase is limited, resulting in lower surface roughness, as reported in a previous study.[29] The small spaces created by this treatment may hinder the penetration of conventional resin composites, which are highly viscous. This limitation likely explains the significantly lower shear bond strength (SBS) observed in PICNs treated with MEP alone, which was consistent with previous studies showing that ceramic materials treated with MEP exhibited a lower bond strength compared to those treated with HF and silane.[16,30,31]

Numerous studies proposed applying hydrophobic resin monomer coating on silanated ceramic surfaces before repairing them with resin composite to improve the bond between resin composite and ceramic interface.[19,20] The viscosity of hydrophobic resin monomer was less than that of resin composite, providing improved flowability on silanated ceramic surface, filling in small pores and irregularities on surface, resulting in a close adaptation and preventing any defects.[19,20] In recent years, universal adhesives containing silane applied on etched ceramic surfaces have been introduced, claiming their simplified application procedure and fewer clinical steps.[32] However, various studies observed a negative effect on bond durability when multicomponent ceramic primers or bonding agents containing hydrophilic monomers were used to repair ceramic.[4,32-34] A previous study demonstrated that the hydrophilic component in dental adhesive applied to silanated feldspathic ceramics led to a decrease in microtensile bond strength over time, despite initially high values.[33] Therefore, the low-viscosity, hydrophobic resin, Heliobond, which lacks hydrophilic components, was chosen as an adjunctive surface treatment before repairing the aged PICNs.

The results from HF+Si+He group showed no significant difference from the HF+Si group, indicating that the hydrophobic resin monomer was not necessary for surface treatment of aged PICNs in the scenario when PICNs was treated with HF and silane. This can be explained by the distinctly greater surface roughness on PICNs.[28] The deep and large valley on the PICNs surface may allow the viscous resin composite to adapt closely to the prepared surface, even without a low-viscosity hydrophobic resin layer. However, recent study was reported that the application of a universal adhesive can achieve similar SBS in HF-treated ceramic, despite no additional silane application.[35] Therefore, when conventional hydrofluoric acid was used as a surface treatment, the necessity of an additional hydrophobic coating in ceramic repair remained inconclusive and was required further study.

A self-etching ceramic primer contains not only TADF but also silanes as a single-component system, designed to simultaneously promote siloxane activity on the prepared surface in one application.[16,24,36] However, the acidic nature of the MEP solution raised concerns about the hydrolytic stability of organosilane, potentially reducing its effectiveness.[37] In addition to acidity, rinsing the surface with water after allowing the solution to react may interfere with silanol activity. Despite these concerns, the silane in MEP has been reported to retain silanol activity after immersion in hot water or thermocycling, as demonstrated using micro MIR-FTIR.[29] This stability was likely attributed to the specific component bis(triethoxysilyl) ethane (BTSE), which is more hydrophobic due to the presence of an ethane group in its structure.[38] BTSE enhanced hydrolytic stability and facilitated the effective performance of organosilane.[39] The results from MEP+He group in the present study also proved the retained activity of silane. The low-viscosity hydrophobic resin was able to flow intimately into the material structure, effectively wetting the MEP-treated surface and creating a well-prepared bonding interface for copolymerization with conventional resin composite materials. This led to SBS values from this group comparable to the HF+Si group, indicating the potential of MEP+He in adhesive performance for repairing aged PICNs.

The composition of the additional resin layer should also be considered. Fillers in adhesive agents enhanced mechanical properties[40,41], probably improving bond between the adhesive and the ceramic substrate. However, an increase in filler size and volume raised viscosity[40,41], negatively affecting wettability and limiting resin penetration into micro-porosities, which may compromise bond strength. Therefore, further studies are needed to investigate the impact of filler composition on the bond strength of repaired PICNs.

When compared to a newly restored material, aged material exhibited a significant decrease in bonding performance.[16,18] Thermocycling is the most commonly used method for accelerating aging simulation, particularly for assessing the thermal effect on the bond interface, which could induce material fatigue due to thermal fluctuations.[15,23,24,26,42-44] Several studies have reported differences in bond strength between immediate and 5000-thermocycled PICNs.[42,45] Additionally, a clinical study indicated that the first instance of chipping in PICNs restoration was observed approximately 11.4 months post-insertion.[11] To simulate intraoral condition for one year[11], 10,000 thermal cycles were performed. The incompatibility of the thermal expansion coefficients of different materials may lead to failure in repaired restorations. Moreover, decrease in bond strength values observed after thermocycling could be attributed to water exposure, which negatively affects polymer stability, resulting in resin composite plasticization and, ultimately, hydrolytic degradation.[42] In contrast with the *in vitro* study, oral environmental conditions affected wear and degradation of dental restorations.[46,47] Moisture degraded the siloxane bond, resulting in silane hydrolysis and deteriorating the bond over time.[42,47,48] Therefore, a combination of different accelerating aging processes is suggested for further study.

The difference in mechanical properties between repaired ceramic restorations and the less-stiff resin composite used at the fracture site can generate high tensile stresses at the ceramic-composite interface beneath the loaded area.[46] Therefore, further clinical studies are needed to evaluate the long-term survival of repaired restorations. Additionally, newly developed resin composites, which claim to have higher strength than previous formulations, should be investigated for their potential in repairing hybrid ceramic materials.

Conclusions

Aged PICNs can be effectively repaired using either hydrofluoric acid and silane or a self-etching ceramic primer followed by the application of a hydrophobic resin. However, surface treatment with a self-etching ceramic primer alone may be insufficient for achieving optimal repair of aged PICNs.

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Conflicts of Interest

The authors declare no conflict of interest.

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A Delayed Onset Cyst-like Lesion at the Lip after Hyaluronic Acid Filler Injection: A Case Report

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Abstract

Nowadays, lip augmentation has become a key component in addressing cosmetic concerns. In particular, hyaluronic acid (HA) fillers are increasingly used for this minimally invasive procedure. Generally, this procedure is well-tolerated, and major adverse events are rare. However, some delayed complications can occur following HA filler injection. Here, we report a case of a HA-related complication in a 45-year-old female patient, affecting the lower lip. Four weeks after the HA filler application, without any immediate adverse effects, a painless, well-defined border nodule occurred in the wet lip area. This cyst-like lesion was surgically identified and successfully treated with surgical excision. Clinicians should be aware that a case manifesting as a well-defined lip nodule suggests salivary gland cysts, soft tissue tumors and cysts, as well as filler-related nodules. This delayed presentation of HA-related nodule in the lower lip poses unique diagnostic and management challenges.

Keywords: filler, filler complication, hyaluronic acid, lip, mucocele

Introduction

In recent decades, lip augmentation procedures have been developed to address the growing trend of achieving ideal lips and combating signs of aging. Among the various methods available, filler injections have emerged as one of the most common and effective approaches.[1] The evolution of fillers has been remarkable, beginning with bovine collagen injections in the 1980s and progressing to include human collagen, hyaluronic acid (HA), calcium hydroxyapatite, poly-L-lactic acid, silicone, and other formulations.[2,3] The ideal skin filler is expected to offer several essential characteristics. It should be biocompatible, allowing for seamless integration with the body's tissues. Moreover, it should be removable when necessary, cost-effective, hypoallergenic, have a long-lasting effect, and easy to distribute and store. In the current landscape of cosmetic procedures, HA dermal fillers stand out as a preferred choice due to their ability to meet many of these criteria. HA, regardless of its source–be it from animals, humans, or HA-producing bacteria–possesses the same molecular structure, thereby minimizing the risk of allergic or immunogenic reactions. This lack of tissue or species specificity enhances its safety profile.[2,3] However, the rapid breakdown of original HA by hyaluronidase poses a challenge, as it has a short half-life of only 12 hours. To address this limitation, manufacturers have developed injectable HA skin fillers with enhanced longevity and durability by modifying the cross-linking chain of HA.[2,4] These advancements have significantly extended the duration of HA fillers, allowing patients to enjoy their aesthetic benefits for longer periods with fewer maintenance treatments

Mild pain, erythema, swelling, and bruising at the injection site are common complaints after HA injection.[2] While these symptoms are typical and generally subsided within a short period, the procedure itself is associated with a very low rate of serious complications.[5] One such severe complication, well-documented in medical literature, is blindness, which occurs when the filler is inadvertently injected into vessels around the orbits, such as the supraorbital vessels. The high pressure at the needle's end, coupled with a bolus injection technique, can cause the product to flow backward into the ophthalmic artery, leading to central retinal artery occlusion. Additionally, other uncommon yet significant complications can arise, including vascular infarction, skin necrosis, hypersensitivity reactions, cellulitis, abscess formation, as well as nodules and granulomas. Nodule formation, in particular, presents an intriguing challenge for clinicians. These nodules may manifest as early or delayed onset, with delayed cases occurring more than 4 weeks post-injection.[6] While early nodules are relatively well-documented and managed, delayed onset nodules remain less frequently reported in medical literature.

Our case report focuses on one such instance–a delayed-onset cystic-like complication related to HA filler injection in the lower lip. This delayed presentation of a cystic-like nodule in the lower lip poses unique diagnostic and management challenges. Comprehending the effects of lip augmentation with HA fillers may enables clinicians to administer safe and effective outcomes.

Case Report

We present the case of a healthy 45-year-old woman who received an application of HA on her lower lip at a local esthetic clinic. Even though IRB review is not required, this case report was prepared in accordance with the requirements of the HIPAA regulations. Four weeks after the HA filler application, without any immediate adverse effects, a painless nodule occurred at the wet zone of the lower lip opposite to teeth 32 and 33. The patient did not know the brand of the filler. She denied having lip sucking or biting habits. The lesion was a submucosal cyst-like nodule with a diameter of a centimeter (Figure 1). The patient was treated at the local clinic by hyaluronidase injection a month after the appearance of the lesion, but the lesion did not subside. Three months later, she came to our hospital reporting no change in the size of the lesion. The differential diagnosis was made: mucocele or delayed onset filler nodule. After a discussion with the patient, we decided on treatment by surgical excision of the mass under local anesthesia. The incision was made at the wet area of the lower lip, approximating to the lesion, and the mucosal flap was elevated to explore the lesion. At this point, there was a 3-millimeter dense nodule close to the swelling mucosa (Figure 2). Approximately half a cc of content was found surrounding the dense nodule. The gross feature of the semi-liquid content was translucent, gel-like substance. It is slightly cloudy in appearance and has a viscous texture (Figure 3). The nodule and HA filler-like substance were surgically removed, and the wound was closed after copious irrigation. Unfortunately, the patient strongly declined a pathological examination of the lesion due to economic reasons.

At a month of follow-up, the lesion was grossly cured. The lip was symmetrical without swelling. The scar from surgical excision was placed on the wet lip, which was hardly visible during smiling or speaking (Figure 4).

Figure 1: A nodule at the lower lip opposite to teeth 32 and 33. The lesion was a submucosal cyst-like nodule with a diameter of a centimeter.

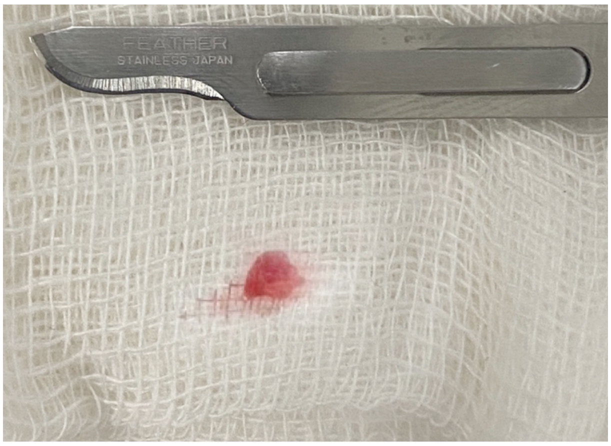

Figure 2: A 3-millimeter dense nodule was surgically removal.

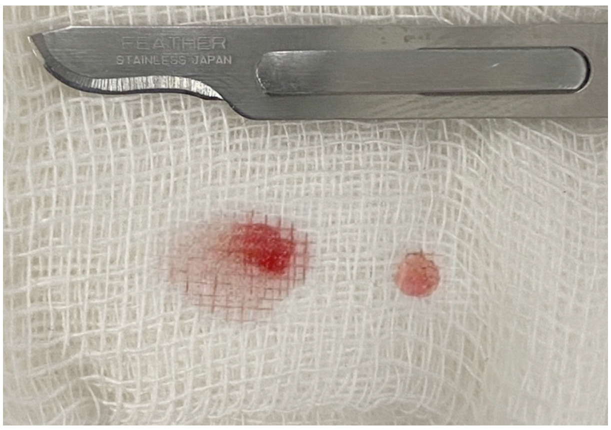

Figure 3: Approximately a half of a cc of HA filler was found underneath the dense nodule.

Figure 4: At a month of follow-up, the lesion was cured. The lip was symmetrical without swelling.

Discussion

Lips, in particular, have historically been a significant feature of the face, contributing to overall attractiveness and a youthful appearance. The lower lip lies between the mouth and the mentolabial sulcus. The sharp demarcation between the colored edge of the lip and surrounding skin is called the vermillion border. The vermillion is a transition layer between the outer, hair-bearing tissue and the inner mucous membrane. The skin of the vermillion is made up of three to five cellular layers and is much thinner compared to the skin on the rest of the face.(7,8) Therefore, lip augmentation procedures aimed at enhancing fullness and promoting a youthful look are frequently sought after in aesthetic medicine. Lip enhancement techniques are classified into surgical and nonsurgical procedures.(1-3) One surgical procedure, the triple V-Y augmentation technique(9), is performed without the use of dermal fillers or implants and aims to expand the vermilion by advancing the labial mucosa forward. Other surgical options for lip augmentation exist as well.(10) Surgical lip implants and autologous fat transfer are used only rarely.(11)

The injection of dermal fillers is the most popular nonsurgical procedure performed to increase the volume and improve the shape of the lips.(12) Semi-permanent dermal fillers–such as calcium hydroxyapatite and poly-L-lactic acid–and permanent fillers are not preferred for lip augmentation because they have an increased risk of irregularity and nodule formation. Hyaluronic acid filler is one of the most commonly used products for lip enhancement.11 HA injections are generally safe with a very low risk of severe adverse reactions, though complications such as skin necrosis, infection, allergic reactions, visual impairment, and nodules or granulomas can occur. Based on a review of lip complication in 17 reported cases,(13) nodules may develop early or delayed after injection, with an incidence of 0.1 to 1.0%. When the HA nodule occurred at more than 4 weeks, the nodule is diagnosed as delayed type.[6] These nodules can be inflammatory, resulting from the body's foreign-body response, or non-inflammatory, typically caused by improper filler placement. Inflammatory nodules may appear days to years after injection, while noninflammatory ones often appear immediately. HA is typically temporary and resorbable, minimizing foreign-body effects, accordingly many non-inflammatory nodules resolve with observation, massage, or hyaluronidase.[5,6]

However, diagnosing lip nodules can be challenging since patients may not report their history of filler injections, which could have been performed weeks, months, or even years prior. A broad range of potential diagnoses commonly includes abscesses, sialadenitis, mucocele, benign salivary gland neoplasms, or malignancy.[14,15] Infections can present early or late in the clinical course and are more commonly associated with single nodules. Involvement of multiple sites suggests a foreign-body granulomatous response more likely. Cases presenting as well-defined lip nodules suggest salivary gland tumors or cysts, such as mucoceles, as well as soft tissue tumors and cysts. Timely and accurate diagnosis of these masses is crucial, as they may mimic neoplasms, which is particularly important given the generally older age group of these patients. Differential diagnoses were summarized in the table 1.

In 2020, Phillip-Dormston[6] provided the management of delayed-onset nodules caused by HA filler. For the inflammatory group, the management starts with non-steroidal anti-inflammatory drugs combined with antihistamines and antibiotics, hyaluronidase, intralesional steroid injection, intralesional laser, and intralesional radiofrequency. If an abscess or fluctuation is present, surgical intervention with incision and drainage may be required for resolution. For non-inflammatory nodules, small or inconspicuous lesions can often be managed conservatively with observation. Hyaluronidase can be administered when the lesion is visible. This guideline was developed for filler-related HA nodules, but in our patient, the lesion was differentially diagnosed as mucocele and an HA-related nodule. We decided on treatment by excision and filler evacuation. A key limitation of this report is the absence of pathological confirmation. However, the author posits that the lesion likely originates from HA filler, based on its distinct gross features and the patient's history of HA filler injection in the affected area.

Conclusions

Practitioners should be aware that a case manifesting as a well-defined lip nodule suggests salivary gland cysts, soft tissue tumors and cysts, as well as filler-related nodules. This delayed presentation of HA related nodule in the lower lip poses unique diagnostic and management

Table 1: A summary of differential diagnoses for cystic-like lesions and related lesions at the lips.

Condition	Key features	Clinical presentation	Treatment
Abscess	Infection, localized swelling, redness, warmth, and/or pain	Single nodule, tenderness, history of trauma or infection	May require surgical drainage
Sialadenitis	A form of inflammation of salivary gland, often due to obstruction	Lip swelling with pain, sometimes the patient has fever	Antibiotics, Drainage rarely needed
Mucocele	Cystic lesion with fluid-filled, caused by a blockage of duct or tear of the gland	Soft, bluish nodule; often associated with trauma (e.g., lip biting, bracket irritation)	Surgical removal
Benign tumor	Non cancerous lesion included benign of salivary gland, lipoma or fibroma	Firm and painless nodule with slow growing	Excision
Malignancy	Hard, fixed nodule, irregular borders, lymphadenopathy	Rapidly growing, painful, with possible ulceration or bleeding	Urgent biopsy for a diagnosis
Hyaluronic acid filler Nodule	Its distinct features and the patient's history of HA filler injection	Well defined, firm and non tender	Observation, massage, hyaluronidase injection; if unresolved, surgical removal

challenges. Despite its rarity, understanding and recognizing such complications are essential for providing optimal patient care and ensuring timely intervention to mitigate potential adverse outcomes.

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Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT-4 to refine and correct certain parts of the English grammar. After using this tool the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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