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REVIEW

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Aims and Scope

Turkish Journal of Orthodontics (Turk J Orthod) is a scientific, open access periodical published by independent, unbiased, and double-blinded peer-review principles. The journal is the official publication of the Turkish Orthodontic Society, and it is published quarterly in March, June, September, and December.

Turkish Journal of Orthodontics publishes clinical and experimental studies on on all aspects of orthodontics including craniofacial development and growth, reviews on current topics, case reports, editorial comments and letters to the editor that are prepared in accordance with the ethical guidelines. The journal's publication language is English and the Editorial Board encourages submissions from international authors.

Journal's target audience includes academicians, specialists, residents, and general practitioners working in the fields of orthodontics, dentistry, medicine and other related fields.

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The editorial and publication processes of the journal are shaped in accordance with the guidelines of the International Committee of Medical Journal Editors (ICMJE), World Association of Medical Editors (WAME), Council of Science Editors (CSE), Committee on Publication Ethics (COPE), European Association of Science Editors (EASE), and National Information Standards Organization (NISO). The journal is in conformity with the Principles of Transparency and Best Practice in Scholarly Publishing (doaj.org/bestpractice).

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2. Drafting the work or revising it critically for important intellectual content; AND

3. Final approval of the version to be published; AND

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Keywords: Each submission must be accompanied by a minimum of three to a maximum of six keywords for subject indexing at the end of the abstract. The keywords should be listed in full without abbreviations. The keywords should be selected from the National Library of Medicine, Medical Subject Headings database (https://www.nlm.nih.gov/mesh/MBrowser.html).

Main Points: All submissions except letters to the editor should be accompanied by 3 to 5 "main points" which should emphasize the most noteworthy results of the study and underline the principle message that is addressed to the reader. This section should be structured as itemized to give a general overview of the article. Since "Main Points" targeting the experts and specialists of the field, each item should be written as plain and straightforward as possible.

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Original Articles: This is the most important type of article since it provides new information based on original research. The main text of original articles should be structured with Introduction, Methods, Results, Discussion, and Conclusion subheadings. Please check Table I for the limitations for Original Articles.

Statistical analysis to support conclusions is usually necessary. Statistical analyses must be conducted in accordance with international statistical reporting standards (Altman DG, Gore SM, Gardner MJ, Pocock SJ. Statistical guidelines for contributors to medical journals. Br Med J 1983: 7; 1489-93). Information on statistical analyses should be provided with a separate subheading under the Materials and Methods section and the statistical software that was used during the process must be specified.

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Type of manuscript	Word limit	Abstract word limit	Reference limit	Table limit	Figure limit
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Review Article	5000	250	50	6	10 or total of 20 images
Case Report	1000	200	15	No tables	10 or total of 20 images
Letter to the Editor	500	No abstract	5	No tables	No media

Tables

Tables should be included in the main document, presented after the reference list, and they should be numbered consecutively in the order they are referred to within the main text. A descriptive title must be placed above the tables. Abbreviations used in the tables should be defined below the tables by footnotes (even if they are defined within the main text). Tables should be created using the "insert table" command of the word processing software and they should be arranged clearly to provide easy reading. Data presented in the tables should not be a repetition of the data presented within the main text but should be supporting the main text.

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Figures, graphics, and photographs should be submitted as separate files (in TIFF or JPEG format) through the submission system. The files should not be embedded in a Word document or the main document. When there are figure subunits, the subunits should not be merged to form a single image. Each subunit should be submitted separately through the submission system. Images should not be labeled (a, b, c, etc.) to indicate figure subunits. Thick and thin arrows, arrowheads, stars, asterisks, and similar marks can be used on the images to support figure legends. Like the rest of the submission, the figures too should be blind. Any information within the images that may indicate an individual or institution should be blinded. The minimum resolution of each submitted figure should be 300 DPI. To prevent delays in the evaluation process, all submitted figures should be clear in resolution and large in size (minimum dimensions: 100 × 100 mm). Figure legends should be listed at the end of the main document.

Where necessary, authors should Identify teeth using the full name of the tooth or the FDI annotation.

All acronyms and abbreviations used in the manuscript should be defined at first use, both in the abstract and in the main text. The abbreviation should be provided in parentheses following the definition.

When a drug, product, hardware, or software program is mentioned within the main text, product information, including the name of the product, the producer of the product, and city and the country of the company (including the state if in USA), should be provided in parentheses in the following format: "Discovery St PET/CT scanner (General Electric, Milwaukee, WI, USA)"

All references, tables, and figures should be referred to within the main text, and they should be numbered consecutively in the order they are referred to within the main text.

Limitations, drawbacks, and the shortcomings of original articles should be mentioned in the Discussion section before the conclusion paragraph.

References

Both in-text citations and the references must be prepared according to the AMA Manual of style.

While citing publications, preference should be given to the latest, most up-to-date publications. Authors are responsible for the accuracy of references If an ahead-of-print publication is cited, the DOI number should be provided. Journal titles should be abbreviated in accordance with the journal abbreviations in Index Medicus/MEDLINE/PubMed. When there are six or fewer authors, all authors should be listed. If there are seven or more authors, the first three authors should be listed followed by "et al." In the main text of the manuscript, references should be cited in superscript after punctuation. The reference styles for different types of publications are presented in the following examples.

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Books with a Single Author: Patterson JW. Weedon's Skin Pahology. 4th ed. Churchill Livingstone; 2016.

Editor(s) as Author: Etzel RA, Balk SJ, eds. Pediatric Environmental Health. American Academy of Pediatrics; 2011.

Conference Proceedings: Morales M, Zhou X. Health practices of immigrant women: indigenous knowledge in an urban environment. Paper presented at: 78th Association for Information Science and Technology Annual Meeting; November 6-10; 2015; St Louis, MO. Accessed March 15, 2016. https://www.asist.org/files/meetings/am15/proceedings/openpage15.html

Thesis: Maiti N. Association Between Behaviours, Health Charactetistics and Injuries Among Adolescents in the United States. Dissertation. Palo Alto University; 2010.

Online Journal Articles: Tamburini S, Shen N, Chih Wu H, Clemente KC. The microbiome in early life: implications for health outcometes. Nat Med. Published online July 7, 2016. doi:10.1038/nm4142

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When submitting a revised version of a paper, the author must submit a detailed "Response to the reviewers" that states point by point how each issue raised by the reviewers has been covered and where it can be found (each reviewer's comment, followed by the author's reply and line numbers where the changes have been made) as well as an annotated copy of the main document. Revised manuscripts must be submitted within 30 days from the date of the decision letter. If the revised version of the manuscript is not submitted within the allocated time, the revision option may be canceled. If the submitting author(s) believe that additional time is required, they should request this extension before the initial 30-day period is over.

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TURKISH JOURNAL of ORTHODONTICS

Original Article

Transfer Accuracy of Three Indirect Bonding Trays: An *In Vitro* Study with 3D Scanned Models

Hilal Gündoğ[1], Ayça Arman Özçırpıcı[2], Hande Pamukçu[2]

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Main Points

- 3D-printed transfer trays were more successful than double vacuum formed and transparent silicone trays for transfer accuracy.
- Deviations were within the clinically acceptable limit for all transfer trays in the horizontal, vertical and transverse planes.
- Deviations in the molars were greater than those in the other tooth groups.
- Bracket deviations were generally toward the buccal direction.

ABSTRACT

Objective: The goal of the current study is to compare the transfer accuracy of two different conventional indirect bonding trays with 3D-printed trays.

Methods: Twenty-two patients' upper dental models were duplicated, scanned and brackets were bonded digitally. Different indirect bonding trays (double vacuum formed, transparent silicone and 3D-printed) were prepared according to three groups. These trays were used for the transfer of the brackets to the patients' models, then models with brackets were scanned. GOM Inspect software was used for the superimposition of virtual bracket setups and models with brackets. A total of 788 brackets and tubes were analyzed. Transfer accuracies were determined according to the clinical limit of 0.5 mm for linear and 2° for angular measurements.

Results: 3D-printed trays had significantly lower linear deviation values than other trays for all planes ($p<0.05$). 3D-printed trays have significantly lower torque and tip deviation values than other groups ($p<0.05$). Transfer deviations were within the clinically acceptable limit for all transfer trays in horizontal, vertical and transverse planes. Deviation values of the molars were higher than those of the other tooth groups for all trays in the horizontal and vertical planes ($p<0.05$). Brackets were generally deviated toward the buccal direction in all tray groups.

Conclusion: The transfer accuracy of 3D-printed transfer trays was more successful than the double vacuum formed and transparent silicone trays in the indirect bonding technique procedure. Deviations in the molar group were greater than those in the other tooth groups for all transfer trays.

Keywords: Indirect bonding, transfer tray, 3D printed tray

INTRODUCTION

One of the main purposes of orthodontic treatment is to align the teeth by placing them in the correct position in the alveolar bone. For this purpose, a wide variety of appliances and different bonding techniques have been used over the years. Accurate placement of brackets is an important factor for the success of the treatment and the incorrect location of brackets can cause undesirable movements of the teeth and a longer treatment time.

Silverman and Cohen[1] developed the indirect bonding technique (IDB) to enhance the accuracy and efficiency of bracket placement in 1972. Thomas[2] improved this bonding method by adding customized-bracket bases using composite resins for bonding brackets on the patient's model. Swetha et al.[3] found that the bond strengths

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were increased with Thomas' method. Numerous studies have been conducted on the effectiveness of the IDB method and this technique has proven to be an effective technique for accurate bracket bonding.[4-6] Additionally, IDB technique has different advantages such as having shorter clinical time, close bond strength to the direct method and being more comfortable for patients.[7,8]

There are different materials and techniques for manufacturing IDB transfer trays. In the classical technique of IDB, brackets are positioned on stone casts and transfer trays are constructed from opaque or transparent silicones, double or single vacuum formed sheets with different thickness.[9,10] With the developing technology, there has been digital progress in the field of orthodontics and IDB techniques have also been digitized. Different companies offer three-dimensional (3D) computer-aided design and computer-aided manufacturing (CAD-CAM) methods for the production of IDB transfer trays. There are various software allowing semi-automatic placement of brackets and the digital design of IDB trays. These trays are usually produced by 3D printing.

There are several advantages of 3D-printed trays over classical IDB transfer trays. The most important advantage of these trays is the all-digital production process; trays can be standardized and the margin of error is minimized.[11] In this method, the need for a physical bracket transfer model is eliminated. Treatment outcome predictions can be made with the features of the software. Besides these advantages, there is a need for a careful technician or clinician who is well-trained in the use of the software used in the digital bonding and design of the 3D-printed tray.

Different IDB techniques were used when comparing transfer accuracies.[10,12-15] Most studies compared the transfer accuracy of IDB methods with direct bonding techniques.[16,17] However, there are fewer studies in the literature comparing 3D-printed trays with conventional IDB transfer trays.[4-6,12-15]

Therefore, this study aimed to compare the transfer accuracy of two conventional IDB transfer trays with 3D-printed trays.

METHODS

This study was approved by Başkent University Medical and Health Sciences Research Board and Ethics Committee (Project number: D-KA20/06) and supported by Başkent University Research Fund. A power analyis was performed by the G*Power software (vers 3.1.9.2; Axel Buchner, Universität Düsseldorf, Düsseldorf, Germany). According to sample calculation using measurements reported by a previous study, 75 brackets for each group were needed to obtain a statistical significance of at least 0.5 mm or 2° difference in terms of transfer error at 80% power and 5% error.[18] Assuming possible drop-out, it was planned to bond twelve upper teeth (first molar to first molar) of 22 patients in every group. Pretreatment upper dental casts of 22 cases were selected from the archive of Başkent University, Department of Orthodontics. The inclusion criteria were permanent dentition with minor crowding (Little's Irregularity Index <3) in the upper dental arch, no missing teeth, no prosthetic restorations, no dental anomalies and no fixed retainers. The selected casts were scanned with a 3 Shape scanner (TRIOS MOVE+, 3Shape Dental Systems, Copenhagen, Denmark) using the same scanning specifications. Twenty-two models duplicated with silicone impression material and 66 models were obtained. All models were cleaned with water and stored in a dry place until the bonding procedure.

Digital models were imported to 3Shape OrthoAnalyzer™ software (3Shape A/S, Copenhagen, Denmark) for virtual bracket placement (Figure 1). 0.018-inch slot brackets and tubes (Mini Master, American Orthodontics, Washington, DC, USA) were selected from the bracket library of the software. The bonding module of the software was semi automatically positioned the brackets and tubes on digital models and minor adjustments were performed by the same author (HG). These digitally bonded models in stereolithography (SLA) format served as reference (before) models for all groups (Figure 1).

Three different indirect bonding trays (double vacuum formed/Group 1, 3D-printed/Group 2, and transparent silicone/Group 3) were prepared (Figure 2). Digital models including the brackets were printed with a 3D printer (Formlabs Form 3, Somerville, MA, USA) using dental resin material (Formlabs, Somerville, MA, USA) for Groups 1 and 3.

In Group 1, double-vacuum trays were produced in a thermoforming device (Erkodent, Erkopress Comotion, Wembley, Australia) with a soft vacuum form (2 mm, Erkodent Erkoflex, Pfalzgrafenweiler, Germany) and a hard vacuum form (0.5 mm, Erkodent Erkodur, Pfalzgrafenweiler, Germany) (Figure 2). In Group 2, transfer trays were designed digitally with ApplianceDesigner™ software (3Shape A/S, Copenhagen, Denmark) and printed with a 3D printer (Formlabs Form 3, Somerville, MA, USA) using laser SLA technology (Figure 2). A flexible, biocompatible Class I resin material (Formlabs IBT, Somerville, MA, USA) was used for the fabrication of the transfer trays using laser SLA technology.

Transfer trays of Group 3 were prepared from transparent silicone impression material (Memosil 2, Heraeus Kulzer, Wehrheim, Germany) (Figure 2) on the resin models. First, the brackets, then the occlusal and lingual surfaces were coated with silicone, and transfer trays were prepared with 3-4 mm thickness. The edges of the trays were shaped with a scalpel to expose the hooks of the brackets, washed and dried with oil-free air.

All transfer trays were numbered according to group. Brackets and tubes were placed manually in the wells of the trays, then the brackets' bases were cleansed with pure alcohol. Each tray was sectioned at the midline to facilitate the bonding procedure.

All bonding procedures of this study were carried out by the same operator with 4 years of experience in the IDB. For bonding of the brackets to the duplicated models, enough light-cured adhesive (Transbond XT, 3M Unitek, Monrovia, CA, USA) was applied to the base of the brackets and a thin layer of primer (Transbond XT, 3M Unitek, Monrovia, CA, USA) was used to disperse the adhesive. The transfer trays were fixed manually onto the models and cured with an LED curing light (Elipar S 10, 3M ESPE, Monrovia, CA, USA) for 45 seconds per tooth. After tray removal, brackets were light-cured for an additional 15 seconds per tooth. Models with brackets were covered with a thin layer of scan-spray (Blue Spray, Dreve/Dentamid, Unna, Germany) to minimize the reflection of the brackets, then the 'after' models were digitized with the same scanner.

"Before" and "after" models were superimposed and evaluated with GOM Inspect software (GOM, Braunschweig, Germany) by a trained observer (Figure 3). Measurements were carried out tooth by tooth. Individual teeth were superimposed with closest point matching "local best fit algorithm" of the software to ensure that the differences were be from the deviations in the bracket position (Figure 4). Twelve reference points on each bracket (occlusal and cervical edges of the mesio-occlusal bracket wing, occlusal and cervical edges of the disto-occlusal bracket wing, mesial edge of the mesio-occlusal bracket wing, distal edge of the disto-occlusal bracket wing, mesial edge of the mesio-cervical bracket wing, distal edge of the disto-cervical bracket wing, buccal edge of the mesio- and disto-occlusal bracket wing, buccal edge of the mesio and disto-cervical bracket wing), and six reference points on each tube (occlusal and cervical edges of the mesio-occlusal part of the tube, occlusal and cervical edges of the disto-occlusal part of the tube, mesial and distal edges of the middle of the tube) were determined on the before models, and alterations in the bracket positions were evaluated (Supplementary Table 1). The positional deviation on the X, Y, and

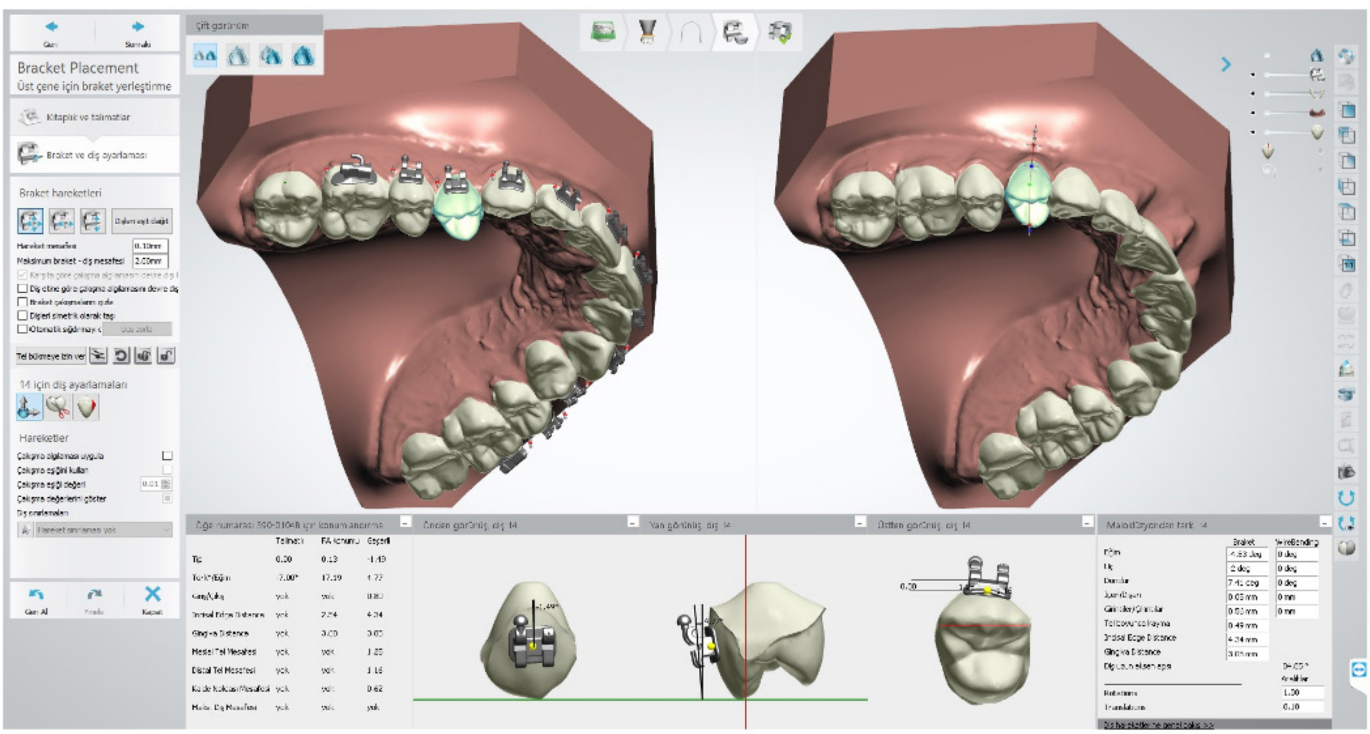

Figure 1. Virtual bracket placement in 3Shape OrthoAnalyzer™ software

Figure 2. Three different indirect bonding trays **A)** Double vacuum formed tray (Group 1), **B)** 3D-printed tray (Group 2), **C)** Transparent silicone tray (Group 3)

Z planes were calculated for every twelve points. The deviations on the X axis (horizontal) were assigned positive (+) values to the left, and negative (–) values to the right. The deviations on the Y axis (vertical) were assigned (+) values in a downward direction, and (–) values in an upward direction. On the Z axis (transversal), (+) values are assigned for outside deviations and (–) values for inside deviations. Angular deviations were evaluated on the XY (angulation/tip), YZ (torque), and XZ (rotation) planes. The linear bracket deviations were calculated in millimeters (mm) and angular deviations were calculated in degrees (°) within and outside the limits for each tooth.

To calculate intra-observer reliability 60 brackets from five different models were remeasured after a time interval of 20 days and the intraclass correlation coefficient (ICC) was calculated.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics for Windows 21.0 (IBM Corp., Armonk, NY, USA). Because the data did not have a normal distribution, the non-parametric Kruskal-Wallis H test was used for comparisons between groups. Intraclass correlation (ICC; two-way mixed) analysis was used for intra-examiner reliability. P<0.05 indicated a significant difference within the limits of 0.5 mm for linear and 2° for angular measurements, and p>0.05 indicated that there was no significant difference. These limits were selected from the professional standards of the American Board of Orthodontics (Aboriginal) objective grading system.[19]

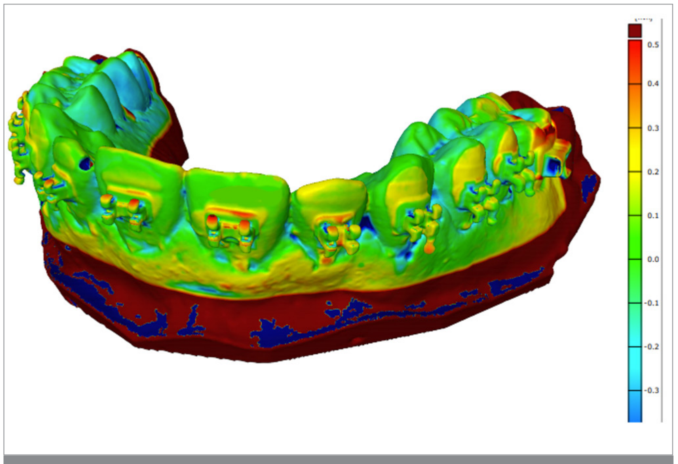

Figure 3. Superimposition of "before" and "after" models with GOM Inspect™ software

RESULTS

ICC values for intra-examiner reliability ranged from 0.993 to 0.998, which demonstrated excellent reliability. A total of 660 brackets and 132 tubes were bonded on 66 casts but four brackets were lost during transfer and not included in the analysis.

The linear and angular deviations are given in Table 1 as means and standard deviations. Transfer deviations were within the clinically acceptable range of 0.5 mm for all tray groups in all planes (Table 1). There were significant differences between the groups for the linear deviations in the horizontal, vertical and transverse planes (p<0.05) (Table 1). Group 2 had significantly lower mean linear deviation values for all planes than the other groups (p<0.05). There were significant differences in angular deviations between the groups for torque, rotation and tip (p<0.05) (Table 1). Group 2 had a significantly lower torque deviation value than Group 1 and Group 3 (1.49 ± 0.66). When the rotation values were examined, Group 3 had a significantly higher deviation value than Group 1 and Group 2 (3.46 ± 0.66). Group 2 had a significantly lower tip deviation value than the other groups (1.71 ± 0.59). The number and percentages of brackets that deviate from the acceptable limits of 0.5 mm and

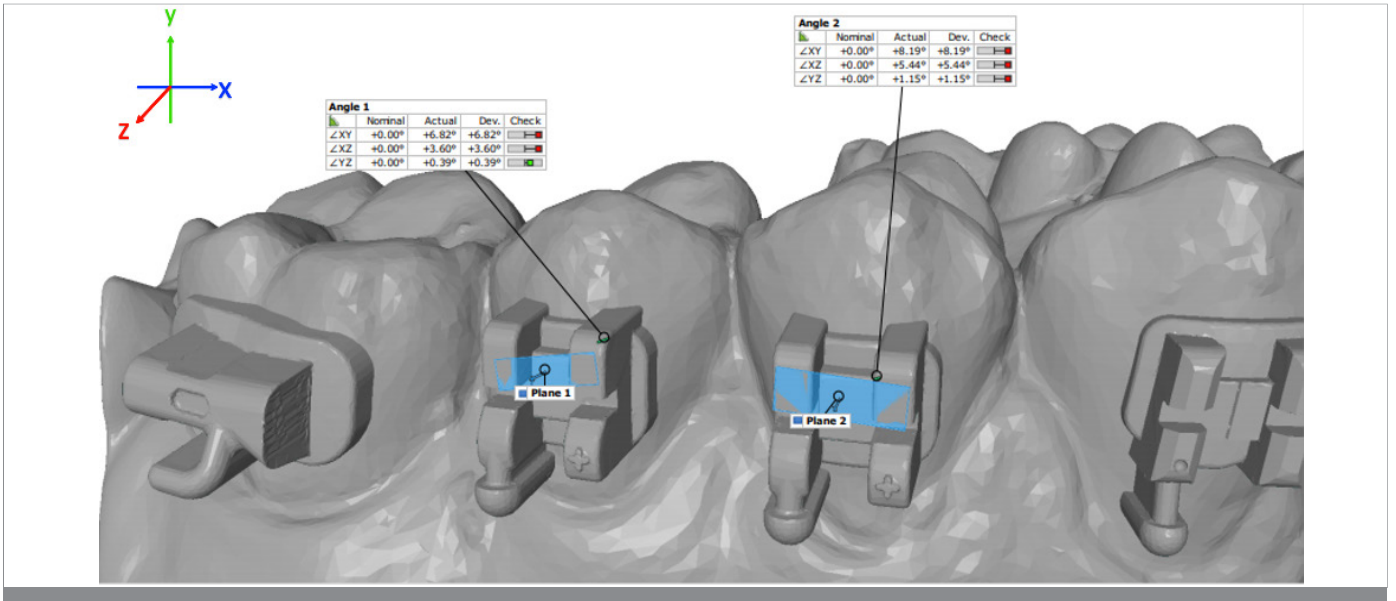

Figure 4. Measurement of deviations in the bracket position with GOM Inspect™ software

Table 1. Intergroup comparisons of transfer deviations of the brackets for linear and angular measurements

		n	Mean ± SD	Paired comparison†	p value
Horizontal (mm)	Group 1	262	0.11 ± 0.05		
	Group 2	264	0.05 ± 0.02	2-1	
	Group 3	262	0.14 ± 0.05	2-3	
Vertical (mm)	Group 1	262	0.22 ± 0.16		
	Group 2	264	0.08 ± 0.04	2-1	
	Group 3	262	0.24 ± 0.14	2-3	
Transversal (mm)	Group 1	262	0.09 ± 0.05		
	Group 2	264	0.06 ± 0.05	2-1	
	Group 3	262	0.09 ± 0.05	2-3	0.0001**
Torque (°)	Group 1	262	2.06 ± 0.34		
	Group 2	264	1.49 ± 0.66	2-1	
	Group 3	262	2.7 ± 0.45	2-3	
Rotation (°)	Group 1	262	2.64 ± 0.36		
	Group 2	264	2.38 ± 0.67	3-1	
	Group 3	262	3.46 ± 0.66	3-2	
Tip (°)	Group 1	262	2.11 ± 0.4		
	Group 2	264	1.71 ± 0.59	2-1	
	Group 3	262	2.58 ± 0.47	2-3	

SD, Standard deviation
†Significant difference between the numbered groups.
**p<0.001

2° were shown in Table 2. It was observed that the number and percentages of brackets outside the limits were low (Table 2).

Intra-group comparisons of tooth groups are shown in Table 3. Deviation values of the molars were significantly higher than those of the other tooth groups in the horizontal and vertical planes for all groups (p<0.05) (Table 3). In Group 1, deviation values of incisors and molars were significantly higher than those of the other tooth groups for torque, and deviation values of the incisors were significantly higher than those of the premolars and molars for rotation (p<0.05) (Table 3). In Group 1, deviation values of canines were significantly higher than molars and premolars for rotation (p<0.05) (Table 3). In Group 3, deviation values of incisors in the transversal direction were significantly lower than those of other tooth groups. There was no significant difference between the tooth groups for angular values in Groups 2 and Group 3 (Table 3) (p>0.05). Percentages of deviated brackets according to direction are given in Table 4. In the buccolingual direction, it was observed that 88.6% of the brackets in Group 1, 92% in Group 2 and 85.6% in Group 3 deviated toward the buccal.

DISCUSSION

The current study was conducted to compare the transfer accuracy of three different transfer trays which were not previously compared digitally. This is of clinical relevance, because double-vacuum formed and silicone materials are commonly used for the preparation of IDB transfer trays, but digital 3D-printed trays are fairly new. Double-vacuum form transfer trays began to be used in the 1990s.[9] Usually, the external layer of these type of trays is rigid, to provide stability, while the internal layer is soft, to allow easy removal of the tray from the brackets.[20-22] These transfer trays were used in Group 1. The innovative process originating from CAD-CAM has enabled a custom-made production in orthodontics. In Group 2, transfer trays were designed and printed digitally from a flexible biocompatible material by laser SLA technology. The transparent silicone impression material was used for the preparation of the transfer trays in Group 3 for using light-cured resin in all groups to provide standardization. These silicone trays were used in indirect bonding studies previously and have been proven to have dimensional stability with high positioning accuracy.[15,23]

In the literature, various methods have been used for the digitalization of study models, such as intraoral scanners, 3D-model scanners, photographs, micro-computed tomography (micro-CT) and cone beam CT (CBCT).[5,24-26] A study compared six intraoral scanners for scanning accuracy and found that all scanners produced acceptable results, but the Trios (3Shape A/S) scanner had the highest precision and reliable results. This scanner was used for the scanning of the models in the

Table 2. Number and percentages of brackets deviated from the acceptable limit

		n	Total	%
Horizontal (mm)	Group 1	5	262	0.02
	Group 2	1	264	0.00
	Group 3	11	262	0.04
Vertical (mm)	Group 1	12	262	0.05
	Group 2	3	264	0.01
	Group 3	11	262	0.04
Transversal (mm)	Group 1	4	262	0.02
	Group 2	0	264	0.00
	Group 3	2	262	0.01
Torque (°)	Group 1	22	262	0.08
	Group 2	19	264	0.07
	Group 3	22	262	0.08
Rotation (°)	Group 1	22	262	0.08
	Group 2	22	264	0.08
	Group 3	20	262	0.08
Tip (°)	Group 1	22	262	0.08
	Group 2	19	264	0.07
	Group 3	22	262	0.08

n, number of brackets deviated from limits

current study. The presence of brackets on the models could cause light reflection, which can lead to image distortion and artifacts.[27,28] A thin layer of scanning spray was applied by an experienced operator to prevent this reflection of the brackets and it is important to apply this spray homogeneously.[29] In this study, GOM software was used to measure the deviation of the brackets by superimposing the "before" and "after" models. Version 8 of this software has the ability to measure the data with a precision of 1 µm and enables a local best-fit to measure teeth separately.[25]

For standardization, conventional brackets with .018-inch slots (Mini Masters Series, American Orthodontics) were used in this study. However, other brackets could produce different results as the design and dimensions of brackets vary among different brands. Therefore, the results obtained from this study may not be valid for all bracket systems.

Bracket positions were found to be within acceptable limits for linear measurements in all groups, and the transfer accuracy of the examined trays was found to be high. While most studies considered these limits adequate, some studies have suggested that smaller deviations could be reliable.[15,24,30] Armstrong et al.[22] stated that deviations of 0.25 mm in incisors were clinically acceptable, whereas deviations of up to 0.5 mm in the other teeth were acceptable. Castilla et al.[12] found that differences of 0.13 mm in the opposite directions were clinically acceptable for adjacently positioned brackets.

The linear deviations for all the planes were less than 0.5 mm in all groups and this was consistent with the findings of many previous studies.[5,6,13,15] 3D-printed trays demonstrated lower linear deviation than the other groups for all planes. The angular deviations were higher than the linear deviations, and this was also similar to the previous studies' results.[5,6,13,15] The angular values of the silicone tray group were higher than those of the other groups.

A recent study by Niu et al.[13] compared double vacuum-formed and 3D-printed transfer trays for bracket transfer accuracy. Their double vacuum form transfer trays were fabricated (soft on the inside and hard on the outside) with a method similar to our method. Moreover, GOM Inspect software was used for the measurements in our study. They showed that 3D-printed transfer trays showed better transfer accuracy than the vacuum form transfer trays, and their linear control was superior to angular control. They also found that the linear values of 3D-printed trays were within the acceptable range suggested by the Aboriginal, while the angular values exceeded the limit. The direction of the deviated brackets in their study was mostly to the occlusal and buccal, which were similar to the findings of this study. The better results of 3D-printed trays can be attributed to the more precise digital design of these trays.

Chaudhary et al.[21] compared 3D-printed trays with the polyvinyl siloxane (PVS) transfer trays. While the position accuracy of the PVS transfer trays on the vertical plane was higher, 3D-printed trays showed higher positional accuracy in all other linear and angular measurements. Additionally, they found that most of the brackets deviated in the buccal direction, this was consistent with our study. They attributed this increased accuracy for the PVS group to the elasticity of the PVS material in contrast 3D-printed tray's more rigid resin or due to incorrect contouring around the edges of the tray. The 3D-printed tray material in our study was not rigid, had sufficient flexibility and stability.

Pottier et al.[15] compared transfer trays made of transparent silicone and 3D-printed trays, and found that both groups produced clinically acceptable values for bracket positions. But they found higher transfer accuracy with the transparent silicone trays, contrary to the results of the current study. The differences might have been caused by the different thickness of the silicone transfer trays, which was 5 mm in their study, on average 3-4 mm in this study. Additionally, silicone transfer trays in their study completely covered the brackets, resulting in reduced bracket mobility. However, 3D-printed transfer trays do not fully cover the brackets. These design differences of the transfer trays could create different results between 3D-printed trays and transparent silicone trays in terms of transfer accuracy.

Jungbauer et al.[6] investigated the selection of transfer trays according to the amount of crowding and suggested choosing a soft transfer tray in case of severe crowding. They advised the use of micro-CTs rather than 3D scanners for transfer accuracy

Table 3. Intra-group comparisons of transfer deviations of the brackets/tubes for linear and angular measurements (results were summarized for incisors, canines, premolars, and molars)

		Group 1			Group 2			Group 3		
		n	Mean ± SD	p value	n	Mean ± SD	p value	n	Mean ± SD	p value
Horizontal (mm)	Molar	43	0.24 ± 0.12	0.0001***	44	0.09 ± 0.09	0.0001***	43	0.29 ± 0.13	0.0001**
	Premolar	87	0.1 ± 0.05		88	0.05 ± 0.03		87	0.15 ± 0.05	
	Canine	44	0.09 ± 0.05		44	0.05 ± 0.04		44	0.1 ± 0.06	
	Incisor	88	0.08 ± 0.07		88	0.04 ± 0.02		88	0.1 ± 0.04	
	Total	262	0.13 ± 0.14		264	0.06 ± 0.06		262	0.16 ± 0.09	
Vertical (mm)	Molar	43	0.35 ± 0.18	0.0001***	44	0.22 ± 0.1	0.0001***	43	0.39 ± 0.14	0.0001***
	Premolar	87	0.21 ± 0.1		88	0.06 ± 0.04		87	0.22 ± 0.13	
	Canine	44	0.16 ± 0.09		44	0.06 ± 0.05		44	0.22 ± 0.15	
	Incisor	88	0.2 ± 0.07		88	0.04 ± 0.04		88	0.2 ± 0.17	
	Total	262	0.23 ± 0.2		264	0.1 ± 0.01		262	0.26 ± 0.19	
Transversal (mm)	Molar	43	0.13 ± 0.1	0.057	44	0.07 ± 0.03	0.002**	43	0.12 ± 0.11	0.266
	Premolar	87	0.08 ± 0.03		88	0.06 ± 0.03		87	0.08 ± 0.02	
	Canine	44	0.08 ± 0.02		44	0.07 ± 0.04		44	0.11 ± 0.05	
	Incisor	88	0.09 ± 0.1		88	0.04 ± 0.02		88	0.08 ± 0.03	
	Total	262	0.09 ± 0.07		264	0.06 ± 0.04		262	0.1 ± 0.06	
Torque (°)	Molar	43	2.2 ± 0.81	0.0001***	44	1.69 ± 1.03	0.276	43	3 ± 0.97	0.333
	Premolar	87	1.64 ± 0.69		88	1.27 ± 0.77		87	2.29 ± 1.09	
	Canine	44	1.78 ± 0.85		44	1.66 ± 0.86		44	2.6 ± 1.36	
	Incisor	88	2.55 ± 0.83		88	1.53 ± 0.71		88	3.01 ± 0.88	
	Total	262	2.04 ± 0.86		264	1.54 ± 0.85		262	2.73 ± 1.11	
Rotation (°)	Molar	43	2.38 ± 0.86	0.012*	44	2.57 ± 0.68	0.716	43	3.73 ± 0.92	0.183
	Premolar	87	2.33 ± 0.61		88	2.29 ± 0.92		87	3.51 ± 0.72	
	Canine	44	2.85 ± 1.03		44	2.34 ± 1.04		44	3.19 ± 0.46	
	Incisor	88	2.98 ± 0.53		88	2.41 ± 0.8		88	3.44 ± 0.43	
	Total	262	2.64 ± 0.82		264	2.4 ± 0.86		262	3.47 ± 0.68	
Tip (°)	Molar	43	2.49 ± 1.35	0.139	44	1.72 ± 0.98	0.606	43	2.87 ± 0.93	0.228
	Premolar	87	2.11 ± 0.46		88	1.88 ± 0.79		87	2.57 ± 0.48	
	Canine	44	2.16 ± 0.66		44	1.51 ± 0.77		44	2.58 ± 0.77	
	Incisor	88	1.89 ± 0.57		88	1.63 ± 0.59		88	2.44 ± 0.47	
	Total	262	2.16 ± 0.85		264	1.69 ± 0.62		262	2.61 ± 0.76	

SD, Standard deviation.
*p<0.05, **p<0.01, ***p<0.001

Table 4. Direction of deviated brackets according to groups (values are given as percentages)

	Direction											
	Mesiodistal		Buccolingual		Occlusogingival		Torque		Tip		Rotation	
Group	Mesial	Distal	Buccal	Lingual	Occlusal	Gingival	BCT	LCT	Mesial	Distal	Right	Left
Group 1	48.48	50.76	88.64	10.61	77.27	21.97	51.14	48.86	49.62	50.38	23.86	76.14
Group 2	42.42	55.3	92.05	7.2	51.14	40.15	53.79	46.21	48.86	51.14	52.27	47.73
Group 3	48.11	51.89	85.61	14.02	67.42	31.06	46.21	53.79	41.67	58.33	28.03	71.97

BCT, buccal crown torque; LCT, lingual crown torque measurements to be more reliable whereas usage of the micro-CT is limited to *in vitro* studies. Contrary to our findings, anterior teeth were found to be the most affected group by bonding errors, but in our study, molars were most affected. This difference could be due to methodological differences and minor crowding of our study groups. The high deviation of the molars can be attributed to the fact that these teeth are located at the end of the transfer trays, in this region more movements could occur during the bonding procedure. There could be bonding differences due to the design of the tubes, which are different and more voluminous than the brackets. Although molars are not evaluated in most of the IDB transfer accuracy studies, some studies found more transfer deviations in molars similar to our findings.[13]

In this study, linear deviations were mostly in the occlusal direction and this result was also consistent with some other studies.[12,14] Generally, brackets are expected to deviate in the occlusal direction as transfer trays are more likely to remain partly in the occlusal direction when they are not fitted completely. However, there are some studies showing more deviations toward the gingival direction, contradicting this finding.[24] This might be due to excessive pressure applied to the flexible transfer tray.

The common expectation for deviations in the buccolingual direction is the occurrence of deviation in the buccal direction, because of the excessive resin on the bracket base. In this study, most of the brackets deviated to the buccal direction, consistent with some studies in the literature.[18] However, movement in the opposite direction is also possible due to excessive sand blasting of the customized resin base.

Only one type of bracket and tube (Mini Master, American Orthodontics) were used in this study, but transfer accuracy in the IDB procedure could be affected by the design and volume of the brackets and tubes. Clinicians can use different brands of brackets and it would not be correct to generalize the results of this study for all bracket types. In future IDB studies, different types and brands of brackets can be compared with 3D-printed transfer trays.

A 3D scanner was used to scan the models with brackets and ICC values for intra-examiner reliability demonstrated excellent reliability in this study. Micro-CTs were found to be more reliable than the scanners in a previous study[6] but the use of micro-CTs increases study costs, and they are not suitable for *in vivo* studies. It is important to apply scanning spray homogeneously to minimize the reflection of the brackets and artifacts in the images. However, such homogeneity might not have been achieved completely as it was applied manually.[31] As a result, any unmeasurable error that may occur cannot be excluded.

This study was an *in vitro* investigation and transfer accuracy could be different in an *in vivo* evaluation. Some factors like isolation problems, saliva, difficulty to see and reach posterior region can affect the positioning accuracy *in vivo* conditions. In an *in vivo* study, the posterior brackets could have a higher incidence of positioning errors.

CONCLUSION

3D-printed transfer trays were more successful than double vacuum formed and transparent silicone trays for transfer accuracy in the IDB procedure. Transfer deviations were within the clinically acceptable limit for all transfer trays in horizontal, vertical and transverse planes. Deviations in the molar group were greater than those in the other tooth groups for all transfer trays. The deviations were generally toward the buccal direction in all groups.

Ethics

Ethics Committee Approval: This study was approved by Başkent University Medical and Health Sciences Research Board and Ethics Committee (Project number: D-KA20/06) and supported by Başkent University Research Fund.

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Supplementary Table 1. Definitions of measuring points on brackets and tubes

	Brackets
Point 1	Occlusal edge of the mesio-occlusal bracket wing
Point 2	Cervical edge of the mesio-occlusal bracket wing
Point 3	Occlusal edge of the disto-occlusal bracket wing
Point 4	Cervical edge of the disto-occlusal bracket wing
Point 5	Mesial edge of the mesio-occlusal bracket wing
Point 6	Distal edge of the disto-occlusal bracket wing
Point 7	Mesial edge of the mesio-cervical bracket wing
Point 8	Distal edge of the disto-cervical bracket wing
Point 9	Buccal edge of the mesio-occlusal bracket wing
Point 10	Buccal edge of the disto-occlusal bracket wing
Point 11	Buccal edge of the mesio-cervical bracket wing
Point 12	Buccal edge of the disto-cervical bracket wing
	Tubes
Point 1	Occlusal edge of the mesio-occlusal part of the tube
Point 2	Cervical edge of the mesio-occlusal part of the tube
Point 3	Occlusal edge of the disto-occlusal part of the tube
Point 4	Cervical edge of the disto-occlusal part of the tube
Point 5	Mesial edge of the middle of the tube
Point 6	Distal edge of the middle of the tube

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Original Article

Influence of Operator Experience on Scanning Time and Accuracy with Two Different Intraoral Scanners - A Prospective Clinical Trial

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Main Points

- Operator experience influences scanning time but not accuracy of scanning.
- The type of intraoral scanner (IOS) used influences the scanning time.
- An operator with an experience of more than 50 to 100 scans can efficiently perform intraoral scanning.

ABSTRACT

Objective: Operator experience and scanner type may influence the time taken and obtained accuracy of intraoral scanning. This study aimed to evaluate the influence of operator experience on the scanning time and correlate the accuracy of the scans taken with two different intraoral scanners (TRIOS 3, 3Shape and i500, Medit).

Methods: In this trial, a total of 20 subjects who required intraoral scanning for orthodontic treatment were included. Intraoral scanning was done with two different scanners, TRIOS 3 and i500. One operator each with high (group 1), medium (group 2) and low (group 3) levels of experience performed intra-oral scanning with two different intraoral scanners. A One-Way ANOVA test was performed to assess the intergroup difference in scanning time and Kendall's tau's correlation test to determine the correlation between the experience of the operator and accuracy among the three groups using the two scanners. Also Independent samples t-test were performed to assess the intragroup differences in scanning time with two different scanners.

Results: The scanning time was influenced by the type of intraoral scanner and operator experience ($p<0.05$). No significant correlation between operator experience and scanning accuracy in the three groups was noted ($p>0.05$). Statistically significant intragroup differences in scanning time between the two scanners were noted ($p<0.05$).

Conclusion: Less experienced operators took more time to scan a subject. Accuracy of scanning among three groups using two scanners was not influenced by the experience of the operator. Scanning with i500 IOS took more time than TRIOS.

Keywords: Accuracy, digital models, intraoral scanners, operator experience, scanning time

INTRODUCTION

Impression of the oral cavity represents an important step, and intraoral scanners (IOSs) enable obtaining data directly without the need of any impression materials or other impression making devices. Digital models are now being widely used for orthodontic diagnosis and treatment planning. They have several advantages over the conventional plaster models that include less storage space, lower risk of damage or breakage, and ease in transferring the data to other clinicians for efficient and extended patient care. Additionally, the 3D models allow prior visualization of hard and soft-tissues, which increases the treatment efficiency, reduces the clinical time and increases patient acceptance and comfort.[1-3] Recent advances in chairside and laboratory digital technology

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have resulted in the widespread use of digital equipment in dentistry.[4,5] Digital models can be obtained through either indirect or direct methods. Indirect methods involve either laser scanning or computed tomographic imaging of the alginate impressions or plaster models, and direct methods involve IOSs. Currently, with the advent of chair-side IOSs, digital dental models can be obtained using the direct method.

In orthodontics 3D models can be used to virtually move teeth. Diagnostic set up using digital models can be used for treatment planning and convincing patients by simulating tooth movements. Digital models are widely used for indirect bonding, aligner planning and fabrication.

Operator experience and scanner type may play an important role in time taken for scanning and the achieved scanning accuracy. To evaluate the accuracy of the IOSs, previous studies used vernier caliper measurements on plaster models[6,7] or on dry skulls as the gold standard, or scans of dental models made from conventional impressions.[8] Operator influence on scanning time and accuracy was assessed in an *in vitro* study by Resende et al.[9] and it was reported that the scanning time reduced as the experience increased.

Since there is a lack of *in vivo* studies evaluating the influence of operator experience on the IOS time and accuracy, this study was proposed to evaluate the influence of operator experience on the accuracy and the scanning time of scans taken with two different IOSs (TRIOS 3, 3Shape and i500, Medit). The null hypothesis of this study was that the operator experience had no influence on the scanning time and accuracy of the scans taken.

METHODS

This prospective study was conducted at the Department of Orthodontics, Saveetha Dental College. The inclusion criteria for the study subjects were: the presence of all permanent teeth from second molar to second molar, Class I malocclusion with mild crowding or proclination requiring orthodontic correction. The exclusion criteria were the presence of any metal or gold crown restorations, tooth agenesis, missing teeth, proximal or occlusal caries. In this study, 20 subjects who applied for orthodontic treatment and required IOS of the maxillary arch were included after fulfilling the eligibility criteria. Informed consent was obtained from the subjects involved in the study.

The sample size calculation was performed using G*Power 3.1 (Franz Faul, University of Kiel, Germany). The total calculated sample size was 60 (20 in each group) based on the mean scanning time for each group obtained from study of Resende et al.[9]. The effect size was 0.64 and the power was set at 0.80.

This study was approved by the Scientific Review Board of Saveetha Dental College and Hospitals (SRB/SDC/ORTHO-1902/21/007). IOS of subjects was carried out with two different scanners - TRIOS 3 (3Shape, Copenhagen, Denmark) and Medit i500 (Medit Corp., Seoul, Korea); i500 connected to a desktop with a specified configuration (Intel R core i7-6700 HQ CPU @ 2.60GHz and 16.0 GB RAM). Three operators with high, medium and low levels of experience scanned the patients. Group 1 with more than 1 year of experience (>100 scans), Group 2 with 3-6 months of experience (<50 and >100 scans), Group 3 with less than 1 month of experience (<10 scans). A dental assistant retracted the cheeks and lips while the scanning was performed. After scanning was done, the primary investigator evaluated the scanned images for completeness to check whether the entire buccal and lingual surfaces of the teeth and sulcus were recorded and whether any incomplete scans were repeated. The scanning time (for both scanners) was derived from the software in seconds (sec). All obtained scans were exported in STL format and the 3D orthoanalyzer software (3Shape, Copenhagen, Denmark) was used with a screen size of 16:9 ratio and all measurements were performed. Intercanine width (ICW) and intermolar widths (IMW) were measured on the 3D models of scans taken by highly, moderately and less experienced operators using TRIOS 3 and i500 IOS separately. ICW was measured between the cusp tips of the right and left canines and the IMW was measured between the central fossae of the right and left first molars.

Statistical Analysis

The data of scanning time data was tabulated in an Excel sheet and transported to IBM SPSS software version 23.0 to perform descriptive statistics. Shapiro-Wilk's test ($p<0.05$) showed that the parameters assessed were normally distributed. One-Way ANOVA was performed to assess the intergroup difference in scanning time and Kendall's tau's correlation test was performed to determine the correlation between the experience of the operator and accuracy among the three groups using TRIOS 3 and i500 IOS, respectively. An Independent samples t-test was performed to evaluate the intragroup difference in scanning time with the two different scanners.

RESULTS

The scanning time is influenced by the type of IOS ($p<0.05$) and by the operator experience ($p<0.05$). Less experienced operators took significantly more time to perform the scans compared with moderately and highly experienced operator (Table 1). Table 2 shows the post hoc results of the intergroup difference in scanning time with 3Shape scanner. Scanning time differences between groups 1 and 3 and groups 2 and 3 were significant ($p<0.05$) with higher scanning times in group 3 followed by group 2. Table 3 shows the post hoc results of the intergroup difference in scanning time with i500. Scanning time differences between groups 1 and 3 and groups 2 and 3 were significant ($p<0.05$).

Operator experience does not influence the accuracy of the scans ($p>0.05$) (Table 4). There was a statistically significant difference in scanning time between the two types of IOS used and more time was needed for the i500 IOS ($p<0.05$) (Table 5).

Table 1. Comparison of scanning time and interdental widths among groups by One-Way ANOVA test

Variables	Type of scanners	High experience Mean ± SD	Moderate experience Mean ± SD	Low experience Mean ± SD	p value
Time (sec)	TRIOS 3	96.75 ± 5.21	106.60 ± 3.83	150.50 ± 15.28	0.000***
Intercanine width (mm)		34.77 ± 2.16	34.86 ± 2.61	35.32 ± 2.70	0.763
Intermolar width (mm)		46.45 ± 2.58	47.06 ± 3.15	46.73 ± 2.90	0.799
Time (sec)	i500	107.05 ± 6.35	113.80 ± 4.58	175.05 ± 28.74	0.000***
Intercanine width (mm)		34.58 ± 2.30	34.59 ± 2.34	35.28 ± 2.49	0.569
Intermolar width (mm)		46.49 ± 2.38	47.37 ± 2.49	46.72 ± 2.40	0.500

sec: second
***p<0.001

Table 2. Results of the post hoc test regarding TRIOS 3 scanning time of high, moderate and low experienced operators

Levels of experience	Mean difference	p value	95% Confidence interval
High experience / Moderate experience	-9.85	0.005**	-17.14 to -2.56
/ Low experience	-53.75	0.000***	-61.04 to -46.46
Moderate experience / High experience	9.85	0.005**	2.56 to 17.14
/ Low experience	-43.90	0.000***	-51.19 to -36.61
Low experience / High experience	53.75	0.000***	46.46 to 61.04
/ Moderate experience	43.90	0.000***	36.61 to 51.19

**p<0.01, ***p<0.001

Table 3. Results of the post hoc test regarding i500 scanning time of high, moderate and low experienced operators

Levels of experience	Mean difference	p value	95% Confidence interval
High experience / Moderate experience	-6.75	0.434	-19.84 to 6.34
/ Low experienced	-68.00	0.000***	-81.09 to -54.91
Moderate experience / High experience	6.75	0.434	-6.34 to 19.84
/ Low experienced	-61.25	0.000***	-74.34 to -48.16
Low experience / High experience	68.00	0.000***	54.9 to 81.09
/ Moderate experienced	61.25	0.000***	48.16 to 74.34

***p<0.001

Table 4. Correlation between interdental widths and operator's experience (Kendall's tau's correlation test)

Variables	r	p value
Intercanine width (TRIOS 3)	0.107	0.299
Intercanine width (i500)	0.109	0.289
Intermolar width (TRIOS 3)	0.003	0.978
Intermolar width (i500)	0.048	0.639

Table 5. Comparison of scanning time of different intraoral scanners within groups by Independent samples t-test

Groups	Scan time (sec) Mean ± SD	p value
High experience (TRIOS 3)	98 ± 1.0	0.007**
High experience (i500)	106 ± 4.0	
Moderate experience (TRIOS 3)	106 ± 3.82	0.011*
Moderate experience (i500)	111 ± 6.0	
Low experience (TRIOS 3)	144 ± 10	0.029*
Low experience (i500)	176 ± 70	

DISCUSSION

With the development of digital technologies, IOSs have largely replaced plaster models as they are more time saving and do not require space for storage.[10-13] The ability to directly capture all dental arch information of the patient, and consequently their 3D models, without using conventional physical impressions, is one of the most important advantages of optical impressions.[14-17] Digital scanners can introduce inherent errors of alignment within the software, and the effects of the scan type, scanner time, and operator experience on the definitive results are unclear.[11,18-20] Hence, it is critical to assess the operator experience in scanning and the obtained accuracy.

In our study, we noted that the scanning time is influenced by the experience of the operator ($p<0.05$). Highly experienced operator took less time for intraoral scanning than the moderately and the less experienced operators. This is in accordance with a study by Sun et al.[21], showing that scanning time is likely to decrease as the operator experience increases. Hence null hypothesis was rejected in the present study.

The results of this study showed that the accuracy of the scans didn't depend on the experience level of the operator ($p>0.05$). The type of scanner influenced the scanning time irrespective of the operator's experience. There was a significant difference in scanning time between the two types of scanners ($p<0.05$). In an *in vitro* study by Resende et al.[9], the influence of operator's experience on the scanning time and accuracy of the scans was evaluated and they concluded that the accuracy of IOSs was influenced by experience of the operator, type of IOS, and scan size. This study reported that the accuracy of the scans improved with the operator's experience, which is conflicting with our findings. This can be due to the differences in the study design.

According to previous studies, there is a learning curve in adapting to the IOSs, and this aspect must be considered with attention.[19,22-24] Learning curve and level of experience was central to the scan time for both scanners. According to our study the less experienced operator took significantly longer time compared to the moderately and highly experienced operators. There was also a significant difference between moderately and highly experienced operators, with highly experienced operator taking less time.

According to a study by Schieffer et al.[25], digital models of permanent dentition are equally acceptable alternatives to stone models. They concluded that the virtual model measurements were reliable as measurements made on stone models and the results were influenced by operator experience.[25] The accuracy of the scans obtained can be explained as how far the measurements deviate from the measurements obtained on the standard plaster models.[26] Evaluation of the accuracy of digital scans has been reported in the literature to be accurately analyzed with sophisticated 3D software programs. To evaluate the accuracy of the scans taken by operators with different experience levels, parameters like the intercanine and intermolar widths were measured on 3D models using 3Shape ortho analyzer software. The results of our study showed that there is no significant difference in the accuracy of the scanning among the three groups. Irrespective of the type of scanner used or the operator experience, the accuracy of the scans was excellent, implying that even an operator with minimum scanning experience can obtain accurate scans.

In vitro studies assessing similar parameters have been reported in the literature, unlike this study.[9] Studies by Patzelt et al.[27] and Grünheid et al.[28] reported on the accuracy of four different IOSs and they included operators who already had IOS experience so the experience of the operators cannot be taken as a factor affecting the accuracy and IOS time.

The limitations of this study include a smaller sample size even though a prior sample size was calculated and the trueness and precision of the scanners were not evaluated. Also more operators could have been included. Future studies should be conducted to address the aforementioned limitations.

CONCLUSION

The following conclusions can be drawn from our study:

1. The scanning time is influenced by the experience of the operator and the type of scanner. Scanning time is reduced with the higher experience of the operators.

2. The accuracy of scanning was not related to the experience of the operator.

3. More time was required scanning with i500 scanners than with TRIOS 3 scanners.

Ethics

Ethics Committee Approval: This study was approved by the Scientific Review Board of Saveetha Dental College and Hospitals (SRB/SDC/ORTHO-1902/21/007).

Informed Consent: Informed consent was obtained from the subjects involved in the study.

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Original Article

Apical Root Resorption of Endodontically Treated Teeth after Orthodontic Treatment: A Split-mouth Study

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Main Points
- The endodontic treatment did not increase the apical root resorption.
- Orthodontic treatment with extraction increased the apical root resorption in vital teeth unlike endodontically treated teeth.
- The quality of the root canal treatment had no critial effects on root resorption.

ABSTRACT

Objective: The influence of pulp status on orthodontically induced root resorption has attracted attention. The purpose of this study was to compare orthodontically induced root resorption in endodontically treated teeth and their contralateral vital teeth in a split-mouth design.

Methods: The sample included 173 patients who had at least one endodontically treated tooth, and their vital contralateral teeth served as the control group before the completion of orthodontic treatment. Apical root resorption measurements were performed by the comparison of digital panoramic X-ray images obtained at the beginning and at the end of the orthodontic treatment. Kruskal-Wallis, Mann-Whitney U, and Wilcoxon tests were used for statistical analysis.

Results: There was no statistically significant difference in apical root resorption between the endodontically treated teeth and the contralateral teeth ($p>0.05$). Sex and tooth type had no effect on apical root resorption both in the endodontically treated teeth and the contralateral vital teeth ($p>0.05$). Orthodontic treatment with extraction caused more apical root resorption in the vital teeth than in the endodontically treated teeth ($p<0.05$). The quality of the endodontic treatment had no significant influence on apical root resorption ($p>0.05$).

Conclusion: Endodontic treatment does not produce greater apical root resorption compared with the vital teeth.

Keywords: Apical root resorption, orthodontic treatment, root canal treatment, endodontic treatment

INTRODUCTION

Apical root resorption may occur because of mechanical or chemical stimuli including various etiological factors such as infection, trauma, pressure, or orthodontic treatment.[1] Orthodontically induced root resorption has been accepted as a serious complication for a long time.[2] Apical root resorption during active orthodontic treatment was shown in 1927.[3] After that, many studies have revealed the correlation between orthodontic treatment and resorption. In these studies, it was stated that age, sex, orthodontic treatment time, amount of the orthodontic forces, and type of tooth movement (with/without extraction) may have a role in apical root resorption.[4-8]

In addition to numerous studies examining the relationship between root resorption and orthodontic treatment, the influence of pulp status on resorption has attracted attention. However, there are contradictory results

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regarding apical root resorption due to orthodontic forces in teeth which are treated endodontically. It is still unclear whether endodontically treated teeth (ETT) differ in terms of resorption compared to vital teeth after exposure to orthodontic forces. Some studies have shown no significant differences in root resorption between vital and root-filled teeth.[9-12] There are also studies reporting that endodontically treated teeth are associated with less root resorption than contralateral teeth with vital pulp.[13-15] Moreover, an animal model study reported that ETT showed greater cement loss than vital teeth after tooth movement.[16]

This split-mouth study compared root resorption associated with orthodontic treatment in teeth with root canal filling and contralateral teeth with vital pulp. The null hypothesis was that there is no difference between ETT and contralateral vital teeth (CVT) in terms of apical root resorption.

METHODS

This split-mouth study was approved by the Non-Interventional Research Ethics Committee of the Bezmialem Vakif University (19/363). Informed consent was received from the patients for their orthodontic treatments.

The patients were selected after a review of 1780 patient records from the archive of the Bezmialem Vakif University Faculty of Dentistry, Department of Orthodontics. The sample was selected from among patients in the archives who were treated from 2010 to 2019.

The following inclusion and exclusion criteria were applied during the examination of the radiography images of 1780 patients. Two hundred and sixty-three patients were excluded from the study because their duration of orthodontic treatment had not yet exceeded 1 year. Among the remaining 1517 patients, 204 had endodontically treated and CVT. Thirteen patients were excluded from the study because they did not comply with the periapical index scoring system that was used in the study, which is the system that was introduced by Ørstavik et al.[17] This scoring system allows the recording of apical periodontitis on radiographs. The system also provides a 5-point ordinal scale ranging from 1 (healthy) to 5 (severe periodontitis with exacerbating features). Furthermore, 8 patients were excluded due to noticeable incisal/occlusal changes, and 10 patients did not have panoramic radiographs that allowed precise measurements. The sample size calculation was performed using the data of a study comparing the amount of root resorption between endodontically treated and vital teeth.[15] That previous study indicated that the amounts of mean apical root resorption were 0.47 ± 0.53 mm and 1.40 ± 1.19 mm for endodontically treated and vital teeth, respectively.[15] G*Power (version 3.0.10) was used to calculate sample size. Accordingly, we estimated that a minimum sample size of 44 subjects was required for detecting statistically significant differences in the orthodontically induced root resorption, to reach a 90% power at the 5% level of significance. More patients than the initially estimated number of patients were included in this study to increase the power of the study and obtain more precise results. Therefore, 110 female (18.78 ± 6.55 years) and 63 male (18.03 ± 4.83 years) patients with a mean age of 18.5 ± 5.98 years were included in this study. The mean orthodontic treatment duration of the patients was 27.87 ± 9.2 months (Table 1). All 173 patients were treated using fixed conventional brackets (Roth prescription, 0.018-inch slot) and general archwire sequences of 0.016-inch nickel-titanium to 0.016x0.022-inch stainless steel (G&H Orthodontics, Franklin, IN, USA). The inclusion and exclusion criteria were as follows.

Inclusion criteria: (1) patients treated using only fixed orthodontic appliances, (2) presence of a tooth subjected to root canal treatment before orthodontic treatment, (3) orthodontic treatment continued for at least 1 year, (4) presence of contralateral teeth that had radiographically normal periapical anatomical structures (intact lamina dura and periodontal ligament space) and had never undergone invasive pulp treatment, (5) good-quality panoramic radiographs before and after orthodontic treatment.

Exclusion criteria: (1) ETT with periapical indices 3, 4, and 5 scores in pretreatment radiography, (2) ETT with excessive root resorption, (3) atypical dental morphology, (4) teeth with noticeable incisal/occlusal edge changes, (5) cleft lip and palate patients, (6) history of orthognathic surgery, (7) systemic or metabolic diseases.

Digital panoramic X-ray images (Planmeca Promax Digital Panoramic X-Ray Unit, Planmeca Inc, Helsinki, Finland) were obtained at the beginning of the treatment (T0) and at the end of the treatment (T1) and used to define apical root resorption. Digital images were obtained using the Dimaxis Pro 3.1.1 program (Planmeca Inc). The ImageJ software (ImageJ software, 1.37, National Institutes of Health, Bethesda, Maryland, USA) was used for measuring apical root resorption. Scale setting was performed based on changing the known distance in pixels to a distance known in millimeters (16.4 pixels/mm).

The lengths of 237 permanent teeth, including the upper central incisors, upper and lower premolars and molars, were quantitatively measured at T0 and T1. The distal and mesial root lengths were measured for the mandibular molars, and the buccal roots were measured for the maxillary molars and premolars. The crown and root lengths in the panoramic radiographs were calculated at T0 and T1 in the ETT and their contralateral teeth as described in previous studies.[18-20]

1. The distance from the incisal or occlusal edge to the root apex was measured in both ETT and CVT on pre-treatment radiographs (a = initial total length).

2. To obtain intra-patient standardization and exclude any possible distortion of panoramic radiographs at T0 and T1, the distance from the incisal or occlusal edge to the cementoenamel junction was measured in both endodontically treated and contralateral teeth (b = pre-treatment, c = post-treatment).

3. Then, the differences (x = expected total length) were calculated as a factor of foreshortening/elongation used in the measurement of the inciso/occluso-apical length of the tooth.

4. The difference between the expected total length and the final root length (d) was accepted as apical root resorption (Figure 1).[18-20]

Statistical Analysis

Thirty panoramic X-ray images were randomly selected after 2 weeks and re-analyzed to assess intra-examiner agreement. The intraclass correlation coefficient (ICC) was used to assess intra-observer reliability. The mean intra-observer ICC was 0.979 (0.950-0.993), which indicated high levels of agreement between the two measurements.

SPSS (version 15.0; SPSS, Chicago, Ill) was used for the statistical analyses, and the level of statistical significance was set at $p<0.05$. The data were tested for normal distribution by using the Shapiro-Wilk test. Sex, treatment type, and quality of root canal treatment were compared between groups with the Mann-Whitney U test. The Kruskal-Wallis test was performed to detect the differences based on tooth type. The comparison of the panoramic radiographs was performed with the Wilcoxon test.

RESULTS

A total of 346 digital panoramic radiographs from 173 patients were analyzed. The demographic data of the patients at the beginning of the treatment are presented in Table 1.

When the T0 and T1 panoramic radiographs were compared, statistically significant apical root resorption differences were observed in both groups ($p<0.05$) (Table 2).

No statistically significant difference in terms of apical root resorption was found between the ETT and the contralateral teeth ($p>0.05$) (Table 3).

Table 1. Demographic characteristics of the patients

Gender (n)	Male	63
	Female	110
Age (Years; Mean ± SD)	Male	18.03±4.83
	Female	18.78±3.55
	Total	18.5±3.98
Treatment type (n)	With extraction	43
	No extraction	130
Tooth type (n)	Maxillary central	11
	Maxillary molar	54
	Maxillary premolar	35
	Mandibular premolar	20
	Mandibular molar	113
Treatment duration (Months; Mean ± SD)	Male	28.01±10.51
	Female	27.79±8.41
	Total	27.87±9.2

SD, standard deviation.

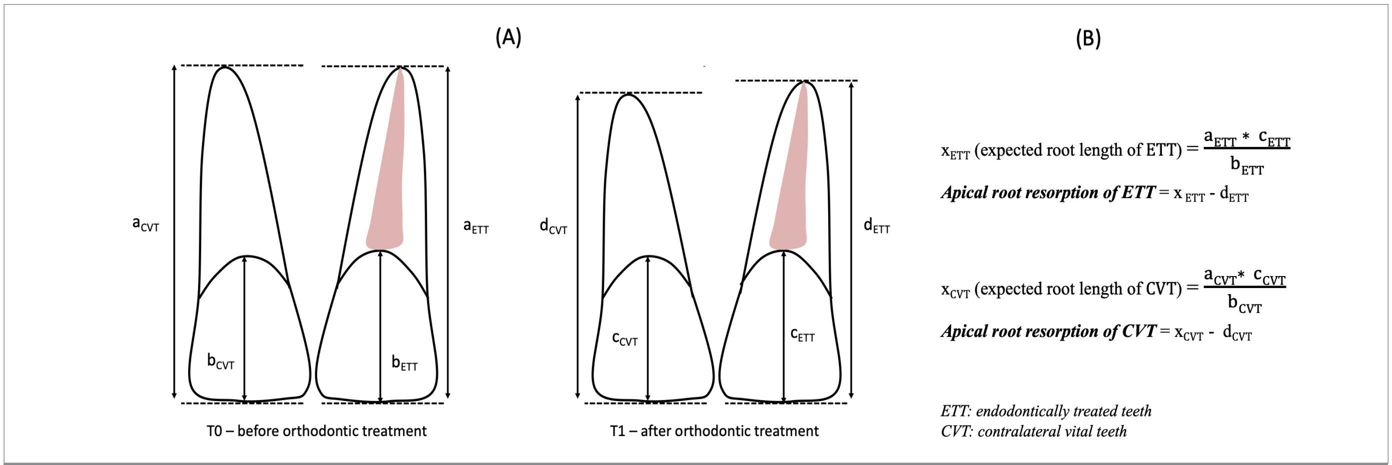

Figure 1. (A) Reference points and lines for measurement (B) Calculation of apical root resorption

While orthodontic treatment with extraction did not have a significant effect on the ETT in terms of resorption, it caused more resorption in the contralateral teeth (p<0.05) (Table 4).

Tooth type or sex had no statistically significant effect on the resorption of the endodontically treated or contralateral teeth (p>0.05) (Table 4). Moreover, there was no statistically significant difference between poor and good quality root canal treatments in terms of the amounts of apical root resorption (p>0.05).

DISCUSSION

A total of 1780 were examined, and 173 of them were included based on the inclusion and exclusion criteria in this split-mouth retrospective study. In studies evaluating orthodontically-induced apical root resorption, digital panoramic radiography, intraoral periapical radiography, and cone-beam computed tomography (CBCT) have been preferred to quantify the degree of root resorption.[10,11,21] Digital panoramic X-ray images were used in this study because of their advantages such as viewing the entire dental arch and their inexpensive and easy to use nature.[22] They also have disadvantages such as errors due to the magnification and superposition of dental structures that may cause the incorrect interpretation of resorption.[22] Moreover, periapical and panoramic radiographs, which allow two-dimensional imaging, can have limitations in terms of the accuracy of apical root resorption measurements.[23] To overcome distortion limitations and standardize the measurements on the digital panoramic radiographs in this study, in the measurement of the closest linear distance from the center of the incisal edge or the cusp tip to the root apex of the teeth, the greatest distance from the incisal/occlusal edge to the cementoenamel junction was also measured to determine the corrected root length. Furthermore, digital panoramic radiographs were preferred in this study since they are the most frequently used method in

Table 2. Comparison of root length before and after orthodontic treatment with Wilcoxon test

	T0	T1	p value
	Mean ± SD	Mean ± SD	
Root length of ETT (mm)	14.7±1.9	13.9±2	<0.001*
Root length of CVT (mm)	15±1.7	14.2±1.8	<0.001*

SD, standard deviation; ETT, endodontically treated teeth; CVT, contralateral vital teeth, *p<0.05.

Table 3. Comparison of apical root resorption values between endodontically treated and contralateral vital teeth with Mann-Whitney U test

ARR in ETT (mm)		ARR in CVT (mm)		p value
Mean ± SD	Median (Min./Max.)	Mean ± SD	Median (Min./Max.)	
-0.73±1.02	-0.7 (-4.8/2.94)	-0.78±1.11	-0.65 (-4.13/1.85)	0.89

SD, standard deviation; ETT, endodontically treated teeth; CVT, contralateral vital teeth; ARR, apical root resorption, Min./Max., minimum/maximum.

Table 4. Summary of independent variables

		ARR in ETT	ARR in CVT
		Mean ± SD	Mean ± SD
Gender	Male	-0.86±1	-0.9±1
	Female	-0.66±0.99	-0.71±1.1
	p value (Mann-Whitney U Test)	0.09	0.06
Treatment type	Extraction	-0.68±1.04	-0.72±1.09
	Nonextraction	-0.92±0.93	-0.96±1.16
	p value (Mann-Whitney U Test)	0.091	0.046*
Tooth type	Maxillary incisors	-1.18±1.3	-1.5±1.16
	Maxillary premolar	-0.48±0.86	-0.78±1.04
	Maxillary molar	-0.64±1.1	-0.78±1.17
	Mandibular premolar	-1.04±1.19	-0.83±1.1
	Mandibular molar	-0.76±0.93	-0.74±1.08
	p value Kruskal Wallis Test	0.25	0.08
Quality of endodontic treatment	Poor	-0.74±1.04	
	Proper	-0.73±1.01	
	p value (Mann-Whitney U Test)	0.84	

*Statistically significant difference, ETT, endodontically treated teeth; CVT, contralateral vital teeth; ARR, apical root resorption, * p<0.05.

the follow-ups of orthodontic treatment, and they have a more acceptable radiation dose than CBCT based on the "as low as reasonably achievable" principle regarding protection against radiation exposure.

For measurements on panoramic radiographs, such as root resorption, where the degree of reproducibility is important, it was suggested that the palatal root of the upper first molar should be considered unreliable, whereas the buccal roots of the upper first molar were reproducible.[24] Besides, more resorption in the distal root was reported in the lower molars.[25] Therefore, the buccal roots of the maxillary molar and the distal roots of the mandibular molar teeth were included in this study. The measurements were performed by one operator, and the ImageJ software, which depends on pixel-based calculation and is commonly used for digitized data analysis, was used.[19]

It has been shown in both histological and radiological studies that resorption occurs with orthodontic treatment, which is usually less than 2.5 mm. A resorption of more than 4 mm was considered as severe resorption.[26,27] In this study, resorption was observed significantly after orthodontic treatment in both the ETT and their contralateral teeth. There was a significant amount of resorption after the treatment compared to the pre-treatment values, and the mean amount of resorption was 0.73 mm for the ETT and 0.78 mm for the CVT. However, no significant difference was observed in the apical root resorption measurements from T0 to T1 between the ETT and the contralateral teeth. In consistency with our findings, Esteves et al.[11] reported that although the mean amount of apical root resorption in vital teeth was slightly greater, there was no significant difference between endodontically treated and vital incisors. However, Wickwire et al.[28] showed that ETT had a higher frequency of root resorption than the control group. Nevertheless, in their studies, most patients had experienced traumatic injuries before their orthodontic treatments, which could have contributed to the resorption process. Another study revealed that vital pulps were resorbed to a significantly greater degree than incisors that had been endodontically treated. Although statistically significant differences were represented, the clinical significance of these differences was minimal.[18]

There is a positive correlation between root resorption and increased treatment duration,[15] and it was stated that the amount of root resorption increases significantly when 12 weeks of force application is reached.[26] In this study, patients whose orthodontic treatment lasted more than a year were included, and their mean treatment duration was 27.87 months. It was stated that the extraction pattern is a critical factor in root resorption. In one study, patients who received 4 first premolar extraction treatments had more resorption than those who were treated without extraction.[29] In accordance with the results of our study, another study demonstrated that orthodontic treatment with extractions represented greater root resorption in vital teeth than in patients without extractions but not on a statistically significant level.[14] It was claimed that orthodontic treatment with extraction compared to non-extraction treatment may cause more irritation in the pulp tissue, more irritation will release more factors that cause resorption, and therefore, less resorption may be observed in patients with ETT since these factors will be released less.[14]

The etiology of resorption is multifactorial and related to orthodontic treatment, as well as individual variables.[27] A study evaluating the effects of sex on external root resorption stated that the amount of root resorption occurring in female patients was greater than that in male patients, but the difference was not statistically significant.[8] In this study, whether the patient was male or female had no effect on resorption in both the ETT and the contralateral teeth. Moreover, the age distribution was limited in this study to better evaluate the effects of endodontically treated and vital teeth on resorption. Since the age distribution of the patients in the study was limited, the effects of age on resorption could not be evaluated. Furthermore, the amount of root resorption varies according to the type of teeth, and this variable was included in this study. It was reported that the maxillary incisors exhibit resorption most frequently, followed by the mandibular incisors and first molars.[27,30] Sharpe et al.[31] suggested that the maxillary central incisors experienced a high incidence of root resorption, followed by molar teeth. Our findings are in accordance with the results of the abovementioned studies.

Kurnaz and Buyukcavus[15] reported that ETT were more resistant to external root resorption than their contralateral vital tooth. In contrast, Huettner and Young[32] revealed that the amount of resorption observed in canal treatment performed under aseptic conditions was not significantly different from that of vital teeth. This study also supported the findings of Huettner and Young[32] in comparisons of the effects of endodontic treatment quality on root resorption, no statistically significant difference was observed between the poor-quality and good-quality root canal treatments. In this study, root canal treatment quality was accepted as good by the following criteria: obturation length (0-2 mm short of length from the radiographic apex) and uniform tapering and density (absence of voids) of root canal filling. Additionally, the data showing scores of 3 or above in the periapical index were excluded. Although the root canal filling was poor, the absence of those with a score of 3 or above according to their periapical index values may have led to the absence of a significant difference between the poor-quality and good-quality root canal treatments. More comprehensive studies are needed to evaluate the effects of the quality of root canal treatment on resorption.

Study Limitations

This retrospective split-mouth study had some limitations highlighted and need to be improved in further studies. Two-dimensional digital panoramic radiographs with less sensitivity than three-dimensional imaging methods were used to measure resorption. The effects of factors such as age and treatment time on root resorption could not be evaluated in detail due to the sample distribution.

CONCLUSION

Within the limitations, the conclusion that may be drawn from this study is that endodontic treatment does not increase apical root resorption. Further studies are needed to evaluate the factors that may cause apical root resorption in ETT and vital teeth after orthodontic treatment.

Ethics Committee Approval: This split-mouth study was approved by the Non-Interventional Research Ethics Committee of the Bezmialem Vakif University (19/363)

Informed Consent: Informed consent was received from the patients for their orthodontic treatments.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - E.D.Ş.; Design - E.D.Ş.; Supervision - E.D.Ş.; Materials - E.D.Ş., A.N.D., N.K.; Data Collection and/or Processing - A.N.D., N.K.; Analysis and/or Interpretation - E.D.Ş., A.N.D., N.K.; Literature Review - E.D.Ş., A.N.D., N.K.; Writing - E.D.Ş., A.N.D.; Critical Review - E.D.Ş., A.N.

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Original Article

Assessment of Changes in Craniofacial Structures, Bite Force and Periodontal Status Following Fixed Functional Appliance Therapy

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Main Points

- FRD appliance was mainly associated with dentoalveolar and subsequent soft tissue changes in Class II Division 1 malocclusion patients.
- Occlusal bite force was reduced after the treatment.
- There was increased plaque formation, gingival bleeding, probing pocket depth with Forsus appliance without any change in clinical attachment levels.

ABSTRACT

Objective: The aim of this study was to determine the effect of Forsus Fatigue Resistant Device (FRD) appliance on craniofacial structures, bite force and periodontal status in Class II malocclusion patients.

Methods: In this prospective interventional follow-up study, thirteen (13) Class II Division 1 patients in their post-adolescent age group with average age of 17.10 ± 1.63 year was treated with Forsus FRD. They were assessed for craniofacial changes, bite force and periodontal status at baseline, after alignment and leveling, after removal of FRD.

Results: Improvement in soft tissue profile was due to significant dentoalveolar changes. There were significant decreases in overjet, overbite, reference line to upper first molar, H angle ($p<0.001$) and significant increases in upper lip to E-line, reference line to lower molar and angular measurements like nasolabial angle, U1 to SN plane, Incisor Mandibular Plane Angle ($p<0.001$). The bite force was significantly decreased on the molar and the incisor region ($p<0.001$). A significant increase in plaque index (PI), gingival index (GI), probing pocket depth was noticed without any significant clinical attachment loss.

Conclusion: Class II correction with Forsus FRD appliance was mainly due to significant dentoalveolar changes. Skeletal changes were non-significant. A decrease in the bite force was found with FRD. The magnitude of bite force was more in males compared with females. The increase in GI, PI, pocket probing depth implies the necessity of oral hygiene and plaque control measures. However, there was no significant change in clinical attachment level.

Keywords: Forsus FRD, fixed functional appliance, bite force, Class II Division I malocclusion, plaque index, gingival index

INTRODUCTION

Class II malocclusion is the most frequent problem encountered in orthodontics after crowding. This problem adversely affects the facial aesthetics and functional status.[1] The most common characteristic of Class II malocclusion is mandibular retrognathia rather than maxillary protrusion.[2] The treatment includes growth modification in growing patients. In contemporary orthodontics, an unparalleled number of options are available for correcting this malocclusion for an orthodontist.[3] Selection of the appliance also depends on the

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growth status of the patient. More skeletal effects have been achieved in adolescent patients than in the post adolescent age group when Twin-block appliance was compared with Mandibular Protraction Appliance (MPA-IV).[4] But Twin-block requires more patient compliance. One of the effective Class II correction device in post-adolescent age group causing more dentoalveolar effect is the Forsus Fatigue Resistant Device (FRD), a compliance free appliance that was developed to overcome breakage problems seen with the Jasper Jumper.[5,6] Forsus FRD applies a constant light force of approximately 200 grams and this device effectively eliminates the use of a long headgear treatment.

Occlusal bite force (OBF) is a key predictor for masticatory performance and it can provide useful data for evaluation of jaw muscle function, muscle activity and as an adjunctive aid in assessing the performance of dentition. Moreover, patients wearing fixed appliances were seen to have more pressure, tension, pain, and sensitivity of teeth. Changes in the activity of elevator muscles and occlusal disturbances during orthodontic treatment are likely to disturb the OBF. Bite force was shown to decrease with the use of Andresen functional appliance and fixed orthodontic treatment.[7,8] FRD also produces dentoalveolar changes; however, the effect of Forsus FRD appliance on the bite force and periodontal health remains unclear.

Thus, it was pertinent to evaluate the effect of Forsus FRD appliance on the bite force and its effect on the periodontal status in the patients undergoing orthodontic treatment. Considering the above evidence, we hypothesize that the use of Forsus FRD appliance will result in a decrease in bite force and will compromise the periodontal health in subjects undergoing fixed functional mechanotherapy. Therefore, the present study measured changes in the craniofacial structures, OBF and periodontal status in the patients undergoing fixed functional appliance treatment with Forsus FRD appliance.

METHODS

A prospective interventional follow-up study was conducted in the Department of Orthodontics and Dentofacial Orthopedics in collaboration with Departments of Periodontics and Mechanical Engineering of Aligarh Muslim University. Subjects included were post adolescent individuals with Class II Division 1 malocclusion and positive VTO. After leveling and alignment, Forsus FRD (L-pin Spring Module, 3M Unitek, Monrovia, Calif, USA) was used as the treatment plan. The average duration of the Forsus FRD was 5.5 months. The study was approved by the Institutional Ethical Committee of Aligarh Muslim University in accordance with the declaration of Helsinki 1964, including 2013 amendments (1029/FM dated 13/07/2018). The subjects who agreed to participate and signed the patient consent form and who fulfilled the following criteria were included in the study.

Inclusion Criteria:

- Age between 14 - 20 years
- Class II Division 1 malocclusion with positive VTO
- Cervical vertebrae maturation index (CVMI) between stages III and V
- Overjet >5 mm and crowding of <5 mm

Exclusion Criteria:

- Patients having posterior crossbite
- Signs and symptoms of TMD
- Craniofacial anomalies and systemic muscle or joint disorders
- Periodontal disease

Taking the power of study (β) 80%, the required sample size in the interventional group was calculated by the formula $n=2\,SD^2\,(Z\alpha/2 + Z\beta)^2\,/d^2$, where SD (standard deviation) of the bite force in a previous study[9] is 72.6 N and effect size or difference (d) in the bite force after the functional appliance is 40 N. The value of Zα/2 is 1.96 and Zβ is 0.842 at type 1 or alpha error of 5%. The required sample size in the intervention arm is 13 subjects.

Out of 250 patients examined for the study from 01/08/2018 to 15/02/2019, 199 subjects did not meet the criteria. Out of 51 subjects who met the selection criteria, 27 declined to participate and 11 did not turn up on appointment. Thus 13 subjects having Class II Division 1 malocclusion with positive VTO were included in the study comprising 6 males and 7 females with an average age of 17.10 ± 1.63 years, using Forsus FRD appliance as a treatment plan. Figures 1 and 2 show a CONSORT flow chart of the clinical study and attachment of Forsus FRD after leveling and alignment.

All the 13 recruited subjects underwent full mouth oral prophylaxis followed by comprehensive oral hygiene instructions The patients were instructed to brush with a horizontal technique and using interdental brush.

All the selected subjects were bonded with MBT Prescription pre-adjusted edgewise bracket with 0.022x0.028 inch slots in both the arches and were aligned with the sequence of NiTi wires and Forsus FRD was delivered after reaching a heavy stainless steel wire of 0.019x0.025 inch. Data were collected at the following time points;

T1: Before treatment

T2: After leveling

T3: After the removal of the Forsus appliance

Craniofacial assessment was performed on the digital lateral head cephalogram manual tracings. Cephalogram of each subject were obtained by orienting them in the natural head position. 23 cephalometric parameters (8 skeletal, 5 soft tissue, 10 dentoalveolar) were measured. Figure 3 shows various craniofacial parameters.

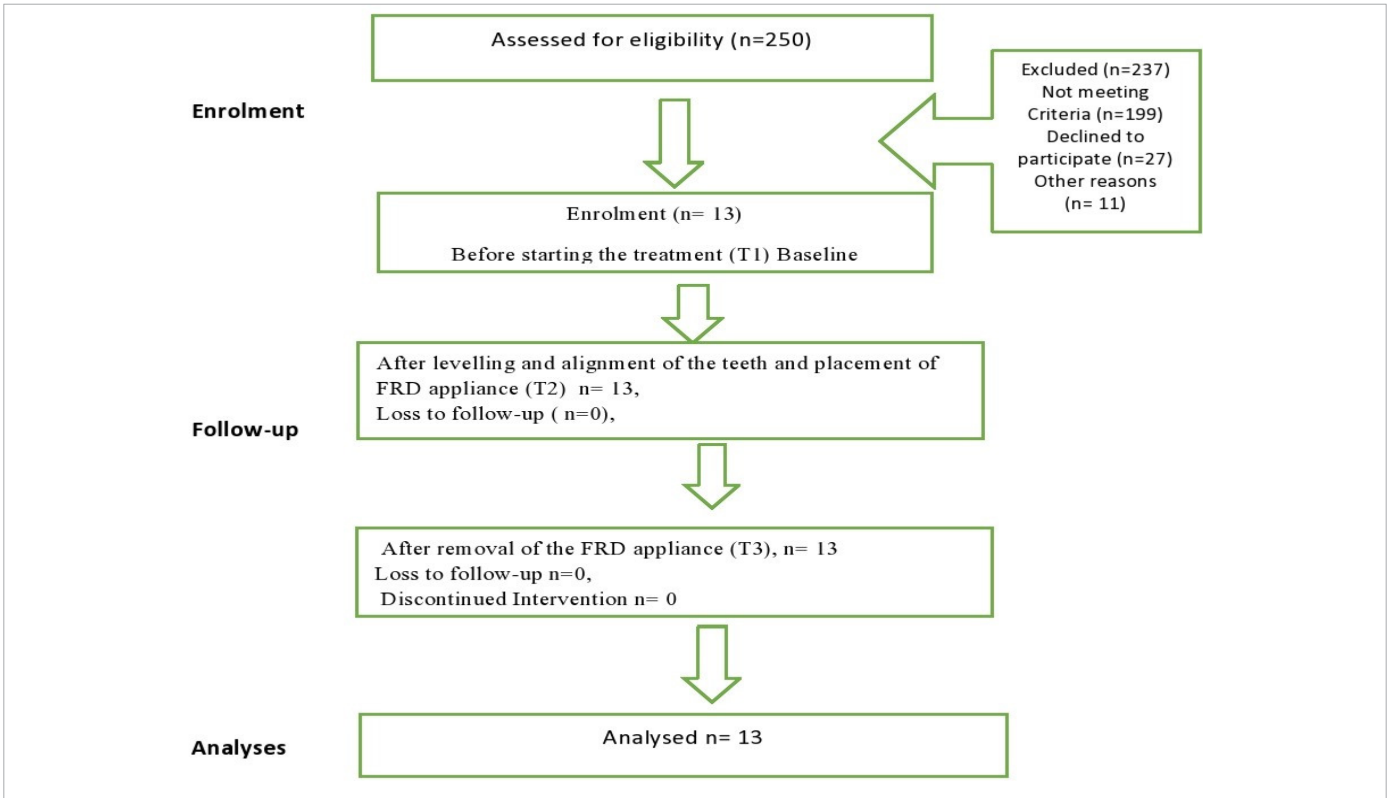

Figure 1. Showing the CONSORT flow of the clinical study

Figure 2. Attachment of Forsus FRD after leveling and alignment
FRD, Fatigue resistant device.

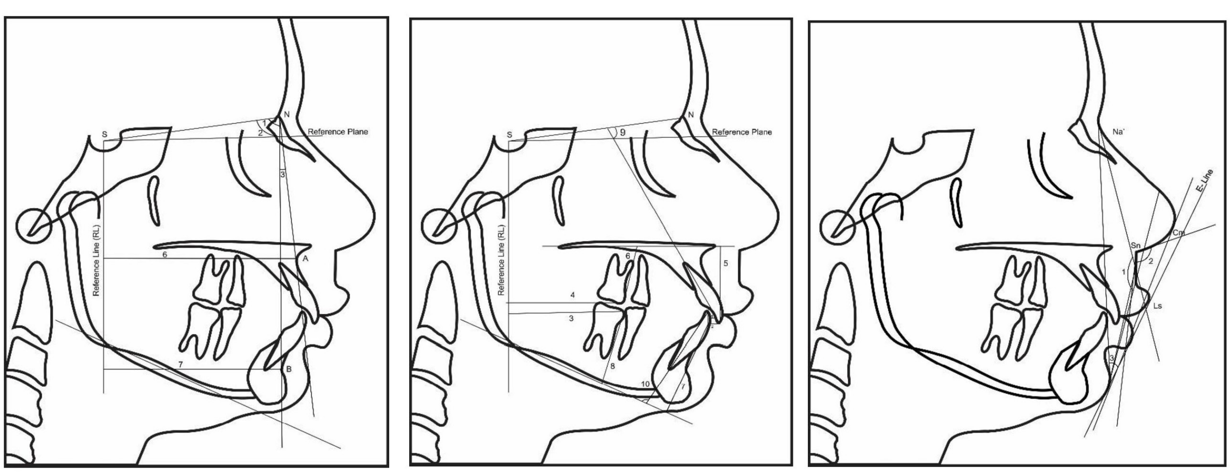

Figure 3. Lateral cephalogram tracing shows skeletal, dentoalveolar and soft tissue variables

Figure 4. Bite force measuring device

Skeletal Variables:

1. SNA, 2. SNB, 3. ANB, 4. Sella Nasion-Mandibular Plane (SN-MP), 5. SN-Palatal Plane, 6. Reference Line to A point (RL-A), 7. Reference Line to B point (RL-B), 8. Jarabak Ratio.

Dentoalveolar Variables:

1. Overjet, 2. Overbite, 3. RL-Lower first molar (M1) (mm), 4. RL-Upper M1 (mm), 5. Upper incisor to the nasal floor (NF) (mm), 6. Upper M1 to the NF (mm), 7. Lower incisor to the mandibular plane (mm), 8. Lower M1 to the mandibular plane (mm), 9. Upper incisor to SN plane (degree), 10. Incisor Mandibular Plane Angle (IMPA).

Soft Tissue Variables :

1. Angle of soft tissue convexity (Na'-A'-Pog'), 2. Nasolabial angle, 3. H- Angle (Na'-Pog'-Tangent to upper lip), 4. Upper Lip-E line, 5. Lower Lip-E line.

Maximum voluntary OBF was recorded using a custom-fabricated device in which a strain gauge load cell was connected to a digital display having a precision of 1 gram. Figure 4 shows bite force measuring device.

All the subject's bite force was measured at the 3 stages of treatment T1, T2, and T3. OBF was recorded at the incisal and first permanent molar region on both right and left sides. Before recording, each subject was instructed to sit upright, looking forward without head support and with the Frankfort plane parallel to the floor. OBF was recorded three times at each side and the incisal region with a 20-second rest between each bite and the average of the reading was taken and compared.

Baseline periodontal parameters; plaque index (PI by Silness and Loe[9], gingival index (GI) by Loe and Silness[10], probing Pocket depth and clinical attachment level (CAL) were evaluated before starting the orthodontic treatment to ensure a non-inflammatory environment for the treatment and none of the patients had clear gingival or periodontal disease initially. Oral prophylaxis was performed in every subject before treatment and after the leveling and alignment of teeth. PI, GI, PPD, CAL at the mandibular incisors and first maxillary molars were considered for periodontal evaluation using University of North Carolina-15 periodontal probe (UNC-15). (Hu-friedy PCPUNC 156, 0417, USA).

Statistical Analysis

Statistical analysis was performed with Statistical Package for Social Sciences (SPSS) software (IBM Corp, Armonk, NY, USA). Descriptive statistics were applied for the mean and standard deviation for each variable. To analyze the changes seen between two stages of the treatment, Paired t-test was used for normally distributed data and the Wilcoxon signed-rank test was used for variables which were not normally distributed. Changes were analyzed between T1-T2, T2-T3, and overall change of treatment as T1-T3 (Table 1). The correlation was checked between bite force and periodontal variables with the Pearson correlation test.

RESULTS

Non-significant changes were found after treatment with FRD appliance in skeletal craniofacial angular measurements (SNA, SNB, ANB and SN-PP angles) and linear measurements (RL-A, RL-B in mm) when compared T1-T2, and after the use of FRD appliance (when compared between T2-T3). Significant changes were found only in SN-MP angle with the increase of 1.69° (when compared between T1-T3) ($p<0.001$) (Table 2).

Upper lip to E line distance showed a significant increase of 0.73 mm and a decrease of 2.53° in H angle with Forsus FRD appliance between T2-T3, ($p<0.01$, $p<0.001$), between T1-T3 ($p<0.001$) ($p<0.01$) (Tables 2, 3). Although changes in the nasolabial angle were non-significant with FRD appliance between T2- T3, it showed a significant increase between T1-T3 ($p<0.05$) (Table 2). Non-significant changes were seen in the lower lip.

With Forsus FRD appliance, overjet and overbite had showed significant improvement between T1-T2, T2-T3, and T1-T3 ($p<0.001$) (Tables 2). Upper Incisor - SN Plane significantly increased ($p<0.001$) with the use of Forsus FRD. Lower incisor showed a proclination of 7° with Forsus when compared T2-T3 and 9.53° during T1-T3 ($p<0.001$). IMPA was significantly increased during period T1-T2, T2-T3, and T1-T3, ($p<0.01$), ($p<0.001$), ($p<0.001$) respectively. The distance of the upper M1 from the RL and from the NF was significantly decreased when compared T2- T3, T1-T3 ($p<0.001$), ($p<0.001$) respectively and distance of lower M1 from the RL was significantly increased during T2-T3 ($p<0.001$) (Table 2).

The bite force significantly decreased during leveling and alignment (T1-T2), this decrease in bite force was 22.29 N, 36.12 N, and 35.19 N at the incisor, right molar, and left molar regions, respectively ($p<0.001$). Similarly, bite force showed significant decreases of 13.83 N, 33.39 N, and, 32.47 N at the incisor, right molar and left molar regions, respectively, when Forsus FRD was used (T2-T3) ($p<0.001$). During (T1-T3) the net decrease in bite

Table 1. Descriptive statistics with mean and standard deviation of all the variables taken for the study at T1, T2 & T3

Skeletal Variables	T1 Mean±SD	T2 Mean±SD	T3 Mean±SD
SNA (º)	80.92 ± 3.33	81.00 ± 3.29	80.85 ± 3.21
SNB (º)	75.30 ± 3.59	75.46 ± 3.55	75.69 ± 3.68
ANB (º)	5.61 ± 1.93	5.54 ± 1.94	5.15 ± 1.57
SN-MP angle (º)	32.15 ± 6.76	32.69 ± 6.99	33.84 ± 6.82
SN-palatal plane (PP) angle (º)	7.92 ± 2.87	8.38 ± 3.01	8.46 ± 2.96
Reference line-A point (mm)	67.91 ± 5.94	68.13 ± 5.39	67.81 ± 5.36
Reference line-B point (mm)	59.25 ± 6.37	59.72 ± 6.29	60.08 ± 6.17
Jarabak ratio (%)	68.53 ± 7.01	67.53 ± 7.25	66.36 ± 7.18
Soft Tissue Variables			
Angle of soft tissue convexity (º)	25.38 ± 5.32	24.23 ± 4.68	22.31 ± 4.01
H angle (º)	21.23 ± 3.63	20.30 ± 3.28	17.76 ± 3.16
Nasolabial angle (º)	102.08 ± 8.89	103.38 ± 9.19	105.38 ± 8.02
Upper lip-E line (mm)	-0.96 ± 1.82	-1.42 ± 1.51	-2.19 ± 1.71
Lower lip-E line (mm)	-2.04 ± 3.50	-1.54 ± 3.22	-1.22 ± 2.81
Dentoalveolar Variables			
Overjet (mm)	9.44 ± 2.37	6.61 ± 1.16	2.46 ± 0.59
Overbite (mm)	6.38 ± 1.94	4.05 ± 1.59	1.96 ± 0.78
Upper incisor-SN plane (º)	61.15 ± 8.42	61.69 ± 6.92	66.30 ± 7.12
Upper incisor-nasal floor (mm)	25.50 ± 3.33	25.78 ± 3.26	26.25 ± 3.34
Upper molar-nasal floor (mm)	20.90 ± 1.68	21.90 ± 1.69	20.42 ± 1.52
Lower incisor-mandibular plane (mm)	44.03 ± 2.89	42.89 ± 2.55	40.21 ± 2.31
Lower molar-mandibular plane (mm)	31.05 ± 3.20	31.83 ± 2.92	32.09 ± 2.44
Reference line-upper molar (mm)	42.24 ± 1.06	42.16 ± 1.11	40.35 ± 1.01
Reference line-lower molar (mm)	38.90 ± 1.33	39.02 ± 1.36	42.83 ± 0.91
IMPA (º)	95.92 ± 8.86	98.46 ± 6.75	105.46 ± 6.86
Bite Force Variables			
Bite force at incisor	62.18 ± 12.9	39.88 ± 8.66	26.04 ± 6.32
Bite force at right molar	124.28 ± 22.29	88.16 ± 16.67	54.77 ± 10.92
Bite force at left molar	124.05 ± 20.06	88.46 ± 15.8	55.99 ± 12.77
Periodontal variables			
Plaque index (PI)	0.78 ± 0.10	1.15 ± 0.14	1.44 ± 0.19
Gingival index (GI)	0.17 ± 0.03	0.38 ± 0.11	0.58 ± 0.11
Probing depth at lower anteriors	1.93 ± 0.09	2.11 ± 0.15	2.30 ± 0.17
Probing depth at upper molar	2.15 ± 0.15	2.71 ± 0.14	2.85 ± 0.12
Clinical attachment level at lower anteriors	0.64 ± 0.16	0.66 ± 0.17	0.67 ± 0.17
Clinical attachment level at upper molar	0.51 ± 0.21	0.53 ± 0.17	0.57 ± 0.16

IMPA, Incisor Mandibular Plane Angle; SN-MP, Sella Nasion-Mandibular Plane

force was 36.13 N, 69.15 N and 68.06 N at incisor, right molar, and left molar regions, respectively and it was significant (p<0.001). It was 58 percent of pre-treatment value at the incisor region, and 55 percent at molar region (Table 2).

Although the bite force significantly decreased at different time intervals when compared between males and females on the right and left M1s in males it was significantly high at different time intervals [T1 (p<0.01), (p<0.05) at T2, (p<0.01), (p<0.05) at T3 (p<0.05). (p<0.05)] respectively. In males the magnitude of bite force was significantly greater than the females at M1 region (p<0.001), (Table 4).

PI and GI showed significant increases during the leveling and alignment phases and in the Forsus FRD treatment phase. PI and GI showed an increase of 0.36 and 0.21 during T1-T2 and 0.29 and 0.21 during T2-T3 respectively. The average probing depth at the anterior and molar regions had showed statistically significant increase of 0.17 mm and 0.14 mm, respectively, during TI-T2 and 0.18 mm and 0.14 mm during the time Forsus FRD. The CAL had showed no significant change at the anterior and molar region (Table 2).

Table 2. Difference in mean of variables between pretreatment and after leveling (T1-T2), before and after removal of Forsus FRD (T2-T3), and before treatment and after removal of Forsus FRD (T1-T3)

	T1-T2			T2-T3			T1-T3		
Skeletal variables	**Mean**	**SE**	**p value**	**Mean**	**SE**	**p value**	**Mean**	**SE**	**p value**
SNA (⁰)	0.07	0.07	0.33	-0.15	0.05	0.33	-0.08	0.12	0.95
SNB (⁰)	0.15	0.40	0.16	0.23	0.17	0.19	0.38	0.21	0.09
ANB (⁰)	-0.07	0.07	0.33	-0.38	0.20	0.13	-0.46	0.69	0.11
SN-MP angle (⁰)	0.53	0.18	0.10	1.15	0.19	0.454	1.69	0.26	0.001*
SN-palatal plane angle (⁰)	0.46	0.26	0.11	0.07	0.13	0.58	0.54	0.11	0.64
Reference line - A Point (mm)	0.22	0.32	0.50	-0.32	0.19	0.129	-0.10	0.22	0.96
Reference line - B Point (mm)	0.46	0.12	0.08	0.36	0.09	0.778	0.82	0.14	0.66
Jarabak ratio (%)	-1.00	0.21	0.72	-1.16	0.10	0.329	-2.17	0.27	0.44
Soft tissue variables									
Angle of soft tissue convexity	-1.15	0.51	0.56	-1.92	0.31	0.216	-3.08	0.18	0.11
H angle	-0.92	0.28	0.21	-2.53	0.24	0.001*	-3.46	0.44	0.01*
Nasolabial angle	1.30	0.79	0.13	2.00	0.96	0.06	3.30	0.34	0.03*
Upper lip - E line (mm)	-0.46	0.23	0.07	-0.76	0.23	0.007*	-1.23	0.68	0.001*
Lower lip - E line (mm)	0.50	1.32	0.13	0.32	0.33	0.38	0.82	0.12	0.52
Dentoalveolar variables									
Overjet (mm)	-2.00	0.32	<0.001*	-4.15	0.28	<0.001*	-6.15	0.70	<0.001*
Overbite (mm)	-2.33	0.70	<0.001*	-2.09	0.39	0.001*	-4.42	0.58	<0.001*
Upper incisor - SN plane (⁰)	1.30	0.81	0.13	4.61	0.18	0.001*	5.92	0.30	<0.001*
Upper incisor - Nasal floor (mm)	0.27	0.32	0.41	0.47	0.23	0.06	0.75	0.13	0.57
Upper molar - Nasal floor (mm)	1.00	0.21	<0.001*	-1.47	0.12	0.003*	-0.48	0.63	0.46
Lower incisor - Mandibular plane (mm)	-1.13	0.31	0.004*	-2.58	0.42	0.001*	-3.82	0.11	<0.001*
Lower molar - Mandibular plane (mm)	0.77	0.23	0.006*	0.26	0.31	0.42	1.04	0.11	0.36
Reference line - Upper molar (mm)	-0.08	0.42	0.84	-1.80	0.22	<0.001*	-1.89	0.41	<0.001*
Reference line - Lower molar (mm)+	0.11	0.52	0.82	3.82	0.19	<0.001*	3.93	0.44	<0.001*
IMPA (⁰)	2.53	0.88	0.04*	7.00	0.27	<0.001*	9.53	0.87	<0.001*
Bite force									
Bite force at incisor	-22.29	1.79	<0.001*	-13.83	1.44	<0.001*	-36.13	2.6	<0.001*
Bite force at right molar	-36.12	2.93	<0.001*	-33.39	2.47	<0.001*	-69.15	4.3	<0.001*
Bite force at left molar	-35.59	2.53	<0.001*	-32.47	2.41	<0.001*	-68.06	3.8	<0.001*
Periodontal variables									
Plaque index	0.36	0.02	<0.001*	0.29	0.03	<0.001*	0.66	0.06	<0.001*
Gingival index	0.21	0.03	<0.001*	0.21	0.03	<0.001*	0.42	0.03	<0.001*
Probing depth at lower anteriors	0.17	0.05	<0.001*	0.18	0.02	<0.001*	0.37	0.05	<0.001*
Probing depth at upper molar	0.55	0.06	<0.001*	0.14	0.07	0.013*	0.70	0.05	<0.001*
Clinical attachment level at lower anteriors	0.02	0.04	0.65	0.01	0.02	0.608	0.03	0.06	0.61
Clinical attachment level at upper molar	0.02	0.11	0.43	0.03	0.01	0.117	0.06	0.07	0.43

*p<0.05 significant, Paired t-test & Wilcoxon signed-rank test, SN-MP, Sella nasion-Mandibular plane; IMPA, Incisor mandibular plane angle; SE, Standard error

Table 3. Comparison of mean of maximum bite force on right molar and left molar region at T1, T2 & T3

	Right molar (Newton)	Left molar (Newton)	p value
	Mean ± SD	**Mean ± SD**	
Before treatment (T1)	124.28 ± 22.29	124.05 ± 20.06	0.979
After leveling (T2)	88.16 ± 16.67	88.46 ± 15.8	0.963
After removal of Forsus FRD appliance (T3)	54.77 ± 10.92	55.99 ± 12.77	0.795

*p<0.05 significant, Unpaired t-test
FRD, Fatigue Resistant Device

Table 4. Comparison of maximum occlusal bite force in male and female at T1, T2 & T3

		Male	Female	Mean difference	p value
		Mean ± SD	Mean ± SD		
Bite force at incisor	T1	69.32±10.52	56.05±10.58	13.26	0.063
	T2	43.86±9.33	36.47±5.26	7.38	0.157
	T3	27.07±4.98	25.16±6.45	1.90	0.603
Bite force at right molar	T1	140.28±14.25	110.57±16.33	29.71	0.008*
	T2	101.90±10.99	76.37±8.31	25.53	0.002*
	T3	61.41±10.01	49.07±6.87	12.33	0.046*
Bite force at left molar	T1	137.99±11.32	112.11±16.47	25.87	0.011*
	T2	99.62±9.54	78.90±12.32	20.72	0.010*
	T3	64.09±10.85	49.05±8.54	15.04	0.033*

*p<0.05 Significant, Unpaired t-test

DISCUSSION

Our study showed that Class II correction achieved with Forsus FRD appliance in post-adolescent age group patients was mainly by maxillary and mandibular dentoalveolar changes without any skeletal changes. Similar findings were reported by Gunay et al.[11] with Forsus FRD and other study reported by Eissa et al.[12] with miniscrew-anchored Forsus FRD. Interestingly, Mahamad et al.[13] showed more skeletal changes with Twin Block appliance as compared to Forsus FRD appliance in growing patients. In a similar recent study, Kalra et al.[14] used Power scope- a fixed functional appliance and found significant skeletal dental and soft tissue changes. Also, Badri[15] in his study reported a mandibular unlocking effect and effective Class II correction with Class II elastics.

We found improvement in the soft tissue facial profile that was associated with upper and lower lip fall due to retroclination of the upper incisors and proclination of lower incisors and reduction in overjet. Similar soft tissue changes were reported by Stromeyer et al.[16] and by Nalbantgil et al.[17] with Eureka spring and Jasper Jumper, respectively.

The overbite also improved due to intrusion and proclination of lower incisors due to an intrusive force vector of Forsus FRD on the lower anterior region and extrusion of mandibular posteriors. Retroclination of maxillary incisors and distalization and intrusion of maxillary molars were considerably noticed due to high pull effect of the appliance since the attachment of Forsus gives a force vector directed both backward and upward on the maxillary molars. It is also below and behind the centre of resistance of maxillary dentition. This finding was consistent with studies using Forsus Nitinol Flat Spring and Jasper Jumper.[18,19] Class-II correction of 5.62 mm was achieved with the use of Forsus FRD in which 68% of molar correction was achieved by mesialization of the mandibular molars and 32% was by distalization of the maxillary molars.

In our study with Forsus FRD appliance, bite force decreased during the leveling and alignment phases and the active treatment phase. Similar findings were reported previously by Therkildsen and Sonnesen[8] and Alomari and Alhaija[20] with fixed orthodontic treatment and they reported a significant decrease in occlusal contact during treatment but it reached the pre-treatment level at post retention. Al-Khateeb et al.[7] in their study with Andresen functional appliance treatment also showed a significant reduction in OBF immediately after treatment. Researchers have reported neuromuscular and skeletal adaptations following mandibular forward positioning induced by the Herbst appliance.[21] A reduction in OBF during the fixed functional appliance can be attributed to changes in masticatory muscle activity.

Functional appliance treatment may directly affect the functional pattern of masticatory muscles.[22] Although these elevator muscles have a good range of adaptation to systemic and local environmental changes, changes in the functional pattern of these muscles cause changes in activity and thereby a reduction in bite force.[23] This study also showed that males have a higher bite force reading than females at the stages and can be attributed to males having larger teeth size and correspondingly greater periodontal area and due to increased activity of masticatory muscles.

Increased plaque accumulation and subsequent inflammation of gingiva were seen during the treatment because of its buccally placed assembly, which makes performing oral hygiene measures more difficult for the patients. There was an increase in the probing pocket depth because of pseudopocket formation due to hyperplasia of gingival tissue or marginal gingivitis, which is usually seen during the fixed orthodontic treatment however there was no change in CAL. So this study reveals that the use of a fixed functional appliance like Forsus FRD does not cause any destructive changes in the periodontium even though it causes gingival inflammation, which is always associated with fixed orthodontic treatment. No available literature to date shows that functional appliance, either fixed or removable causes irreversible change in periodontal structures hence fixed functional appliance like Forsus FRD can be used with proper oral hygiene in periodontally healthy individuals. In periodontally compromised cases in the presence of an active inflammatory condition, the use of fixed functional appliances should be avoided.

The novelty of this study is that it specifically measured the effect of Forsus FRD therapy on the OBF and periodontal status for the first time.

Study Limitations

Since patients applied maximum OBF from a stretched position rather than biting from a relaxed condition of masticatory muscle, the maximum OBF measured in this study was lower than that of the optimal range. Also, the follow-up readings of the occlusal force were not taken after the completion of the treatment.

CONCLUSION

The Forsus FRD appliance was effective in treating Class II malocclusion mainly due to the significant dentoalveolar changes without any significant skeletal changes in post adolescent individuals. Improvement in the soft tissue profile of the patients was owed to the dentoalveolar changes because the lip followed changes in incisor position. The maximum OBF was decreased during the leveling and alignment phases and during the active treatment with Forsus FRD and the OBF value was seen to be higher in males than in females. Increased plaque accumulation and subsequent increase in gingival inflammation were noticed during the treatment, but there was no loss of periodontal attachment with the use of Forsus FRD appliance.

Ethics

Ethics Committee Approval: The study was approved by the Institutional Ethical Committee of Aligarh Muslim University in accordance with the declaration of Helsinki 1964, including 2013 amendments (1029/FM dated 13/07/2018).

Informed Consent: Informed consent was obtained.

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Original Article

Effects of Ballista and Kilroy Springs on Palatally Impacted Canines: A Finite Element Model Analysis

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Main Points

- The von Mises stress values of impacted canines were greater in the Kilroy model.
- The distribution of von Mises stress values of the first premolar tooth was similar in both models.
- Different stress values occurred in the different spring designs.

ABSTRACT

Objective: This study evaluated the stress distribution and displacement on impacted maxillary canines and their adjacent teeth of orthodontic forced eruption using Ballista and Kilroy springs by finite element model (FEM) analysis.

Methods: Two different FEMs applying the same force level on an impacted canine tooth (Model 1: Ballista spring, Model 2: Kilroy spring) were conducted using FEM analysis and the principal stresses, von Mises stresses, and displacements were evaluated.

Results: Von Mises values at the cusp tip of impacted canines were measured as 0.009896 N/mm² in the Ballista model and 0.015334 N/mm² in the Kilroy model. The highest value was measured in the buccal apex of the first premolar in both spring designs. The extrusion was observed in Ballista, and intrusion was observed in the Kilroy model at the apex of the first premolar. The Ballista model showed the highest value (0.003642 N/mm²) at the buccal tip of the first premolar, while in the Kilroy model, the highest measurement (0.002989 N/mm²) was shown at the incisal edge of the lateral tooth.

Conclusion: Von Mises stress values were higher in the Kilroy model at the cusp tip and apical part of the impacted tooth than that in the Ballista model. The highest von Mises stress values were concentrated on the buccal root apex of the first premolar in both models. Although the amount of force applied by the springs was the same, the stress values were different depending on the spring design.

Keywords: Canine impaction, finite element analysis, force, Ballista, Kilroy, impacted teeth

INTRODUCTION

The condition that a tooth can not erupt due to malposition or lack of space is called impaction.[1] Among the impacted teeth, maxillary canines are the second most frequently impacted lesions following the third molar,[2] and the incidence of impacted maxillary canine teeth was reported as 0.92%-2.2% in the literature.[3-5] Approximately two-thirds of the reported impacted teeth were in the palatal position, while one-third of them were in the labial alveolar region.[6,7]

An examination of the literature revealed that lasso wire, threaded pins, gold chains, bands-brackets, eyelets, or attachments have been used in various orthodontic treatment approaches for orthodontic eruption of impacted teeth.[8] Ballista and Kilroy springs are also used for the traction of the impacted canines.[9,10]

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Applied orthodontic forces during the forced eruption of impacted canines create stress areas in supporting tissues and may cause varying degrees of damage to periodontal tissues. Therefore, it is extremely important to maintain the applied forces within physiological limits to avoid side effects on the impacted teeth, surrounding periodontal tissues, and adjacent teeth.[11,12] Temporary anchorage devices can be used to manage the successful orthodontic traction of impacted canines with minimal side effects.[13]

The Ballista spring was introduced by Jacoby[9] in 1979, and the Kilroy spring was invented by Bowman and Carano[10] in 2003. Ballista and Kilroy springs were reported that they deliver light and continuous force on impacted canines due to being twisted on their long axes. Both of these springs were introduced to have no harm on adjacent teeth while the canine was in orthodontic traction,[9,10] therefore it was aimed to compare these two springs in this study.

The finite element model (FEM) can be used to simulate force-dependent stress distributions in different orthodontic treatment approaches as an effective and non-invasive method.[14] Since this analysis is conducted in a virtual environment, it can be reproduced as many times as desired under identical conditions. The standardization of fixed variables provides reliability and makes the analysis valuable.[15]

In this study it was aimed to perform a three-dimensional (3D) simulation, which could not be conducted in clinical studies or animal experiments, and to elucidate the stress distribution of eruption of palatally impacted teeth. The null hypothesis of the study was that there was no significant difference in the force distribution between the Ballista and Kilroy springs.

METHODS

This study was approved by the Istanbul Medipol University Clinical Research Ethics Committee with the decision number 10840098-604.01.01-E.8437. Ballista spring can be made from 0.014, 0.016, or 0.018 inch round stainless steel (SS) wire. It is twisted on its long axis and this bending accumulates its energy. The anchorage part of the wire enters the first or second molar tube and is tied to prevent rotation. Its horizontal part enters the slot of the premolar bracket and can rotate so that the hinge axis is formed. The last part of the spring facing the canine tooth is bent vertically down, when the wire is attached to the tooth with a ligature or elastomeric thread, it transmits the energy, that is received from the horizontal part, to the canine and acts like a Ballista.[9]

The Kilroy Spring slides on a rectangular archwire over the region of the impacted canine and gives a constant force. Bending of the spring can be performed using 0.014 inch or 0.016 inch SS arch wires. The configuration looks like "Kilroy Was Here" graffiti. The vertical loop of Kilroy Spring is perpendicular to occlusal plane when the spring is passive. The spring is activated when a SS ligature is passed through the helix at the end of the vertical loop of the spring and attached to the button on the impacted tooth. The spring gets the support from the archwire and contacts the adjacent teeth with the lateral extensions of the spring.[10]

Two different FEM models were prepared with Kilroy and Ballista springs to apply 60 g of force to a unilateral palatally impacted maxillary canine tooth. The stress distribution was evaluated by finite element analysis.

The models were defined as follows; first model: a Ballista spring (0.016 inch SS) model was formed by applying 60-g force, the second model: a Kilroy spring (0.016 inch SS) model was formed applying 60-g force. A preliminary archive study was previously conducted (Istanbul Medipol University, Ethic Committee number 10840098-604.01.01-E.3649) to determine a realistic localization of the impacted canines. The archive of Istanbul Medipol University Faculty of Dentistry was searched, and 67 cone-beam computed tomography (CBCT) images of impacted maxillary canine cases were examined. In this study, the impacted maxillary canines (N=50) were evaluated by the method of Dağsuyu et al.[16] and root resorption of adjacent teeth was not examined based on the study of Silva et al.[17] 1- In sagittal plane: Impacted canine angulation to the occlusal plane, canine cusp tip and apex distances to the occlusal plane, 2-Coronal plane: Maxillary impacted canine angulation to the midline and lateral incisor; 3-Axial plane: Maxillary impacted canine cusp tip and apex distances to the midline were measured.[16] Subsequently, an average position was determined. Because of the measurements, the left maxillary canine (no 2.3) was accepted to be used in the FEM analysis as the impacted tooth.

To create the geometric model of the upper jaw, tomography image of a fully edentulous adult patient was used. The image was scanned in CBCT (ILUMA, Orthocad, CBCT, 3M Imtec, Oklahoma, USA). Then the volumetric data were reconstructed with a section thickness of 0.2 mm. The sections obtained because of the reconstruction were exported in DICOM 3.0 format. Exported sections were imported into 3D-Doctor (Able Software Corp., MA, USA) software. U-shaped, medium-width, and medium-length alveolar arch shape was chosen for use in this study. During modeling, the width of the alveolar crest was taken as 6 mm and the height as 25 mm based on a previous study.[18] After the decomposition process, a 3D model was obtained with the "3d Complex Render" method and the bone tissue was modeled in this way. Through these software programs, the cortical bone, spongy bone, teeth, and periodontal ligament (PDL) were reflected in the model to show their true morphology. The thickness of the PDL was modeled as 0.25 mm homogenously. After the models were created geometrically with VRMesh software, they were transferred to Algor Fempro (Algor Inc., USA) software in Standart Tessellation Format (STL) for analysis, and thus maxilla and dental building materials were introduced to the software. Material values (modulus of elasticity and Poissson's ratio) describing their physical properties were given to each structure that make up the models. In this study, the moduli of elasticity and Poisson ratios were similar to those in the previous literature.[19,20] The teeth scanned in the x, y, and z axes were combined in Rhinoceros software (Rhinoceros 4.0, 3670 Woodland Park Ave N, Seattle, WA, USA). After merging, the morphology of the teeth was arranged according to the Wheeler atlas. PDL and Lamina Dura tissues were modeled in the parts of the teeth that remained in the bone. The position of the impacted canine (2.3) was modeled according to the position that determined in a preliminary study. Models were made in Rhinoceros software, were placed in the correct coordinates in 3D space and the modeling process was completed. Kilroy and Ballista springs, on the other hand, were manually modeled in 3D software for appropriate sizes.

In the rigid body properties are assumed to be linear, elastic, homogeneous and isotropic in the program. For Algor software, models were filled with mesh. In the meshing process, the models were formed from elements with 8 nodes (brick type). In the FEM analysis, the smallest unit was divided into shapes called "elements", which are expressed as simple geometric models and serve to maintain a constant distance between the nodes to which they are connected.[21] By dividing the models, a finite number of elements are connected to one another at certain points, and these points are called nodes. In the models, displacements are associated with displacements in each element.[22] The final model contained 169283 nodes and 714629 elements for Kilroy spring, 168705 nodes and 713286 elements for Ballista spring. In the modeling phase, the maxillary arch block was formed with 0.016 x 0.022 inch SS archwire in a 0.018 slot Roth bracket system, and the arch wire and bracket system was combined with a 1.0-inch SS trans palatal arch (TPA) that was used as an anchorage unit. After the introduction of the material properties to the system, force was applied and analysis was performed. The force vectors were applied on the button of the impacted canine in two dimensions due to the properties of the Ballista and Kilroy springs. The canine tooth was modeled based on a preliminary study and the mucosa was not present in the model. The exposed surface of the canine was disto-palatal portion of the canine crown and the button was placed in the middle of this surface. The force was applied from the bottom up toward the tip of the spring that terminates toward the impacted tooth.

Principal stresses, von Mises stresses, and displacements in three directions of space were determined by FEM analysis. Principal stresses were used for fragile materials (bone, teeth, etc.), and von Mises values were used for retractable materials (screws, restorations, etc.). In this study, von Mises stress values were formed at the reference point cusp tips, incisal edges and apices of all teeth, including the impacted tooth, and the condensation regions were examined in Ballista and Kilroy models (Figures 1a, b). Total displacement and displacement values in the X, Y, and Z directions were determined in the measurements of the Ballista and Kilroy spring models (Figures 2, 3). X direction displacement: the plus value indicates the buccal displacement for posterior teeth, and the distal displacement for anterior teeth. Y direction displacement: the plus value indicates the distal displacement for posterior teeth, and palatal displacement for anterior teeth. Z direction displacement: the plus value indicates the intrusion, and the minus value indicates the extrusion movement.

The values that obtained in the FEM analysis were the result of mathematical calculations without variance; therefore, statistical analyses could not be performed due to the nature of the study.

RESULTS

When the displacement of adjacent teeth was evaluated, in the Ballista model, the maximum total displacement was 0.001228 mm in the palatal cusp tip of the first premolar tooth, while in the Kilroy model, it was 0.001247 mm in the incisal edge of the lateral tooth.

In the Ballista model, the first premolar buccal cusp tip moved most buccally, while in the Kilroy model, the most buccal movement was in the lateral tooth. In all the cusp tips of first premolars moved palatally in Kilroy model whereas in Ballista model the cusp tips of the first premolars moved buccally (Figures 2, 3).

In the Ballista model, the palatal cusp tip of the first premolar was the most mesially displaced. In the Kilroy model, the incisal edge of the lateral tooth was mesially displaced. In the Ballista model, the lateral tooth was more distally displaced (0.000614 mm) than that in the Kilroy model. The lateral tooth in the Kilroy model was mesially displaced by 0.000441 mm (Figures 2b, 3b).

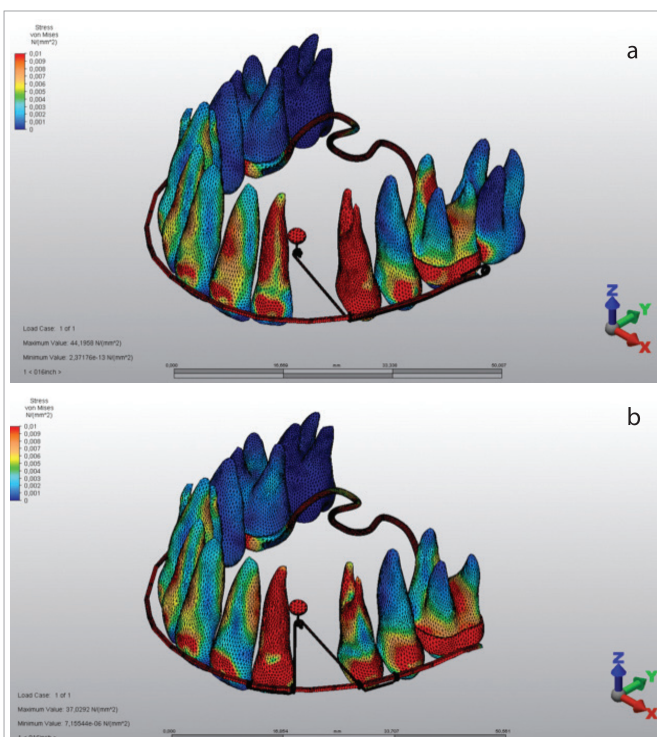

Figure 1. a) Von Mises Stress Values of Ballista Model, **b)** von Mises Stress Values of Kilroy Model

In the Kilroy model, the lateral tooth was intruded (0.000037 mm), while it was extruded in the Ballista model (0.00002 mm). The extrusion was observed at the palatal tip of the first premolar tooth in Kilroy. An intrusion was observed at the first premolar tooth. In both models, the extrusion of the central tooth and intrusion at the buccal tip of the premolar tooth were observed (Table 1), (Figures 2c and 3c).

Apical displacement of adjacent teeth to the impacted canine showed that the greatest total displacement for Ballista was at the palatal tip of the first premolar, whereas for Kilroy, it was at the lateral tooth. While the lateral tooth was displaced 0.000409 mm in Kilroy, the palatal root apex of the first premolar tooth was displaced 0.000495 mm in Ballista.

In the Kilroy model, the apex of the lateral tooth was distally displaced (-0.000351 mm), while in the Ballista model, the palatal apex of the first premolar tooth buccal displaced (-0.000319 mm). The apex of the central and lateral teeth moved buccally in both models except for the lateral tooth in the Ballista model. while the apex of the first premolar tooth in the Ballista model showed buccal displacement, the apex of the first premolar tooth in the Kilroy model showed palatal displacement (Figures 2a and 3a).

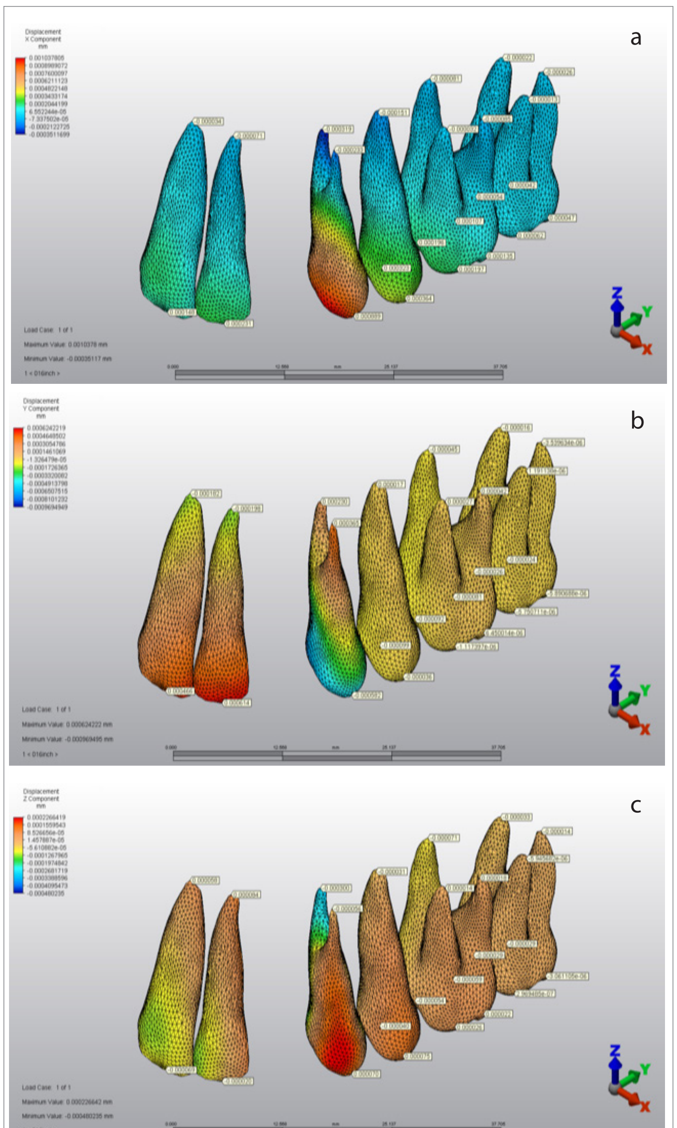

Figure 2. a) Displacement of X-Direction Values of Ballista Model, **b)** Displacement of Y-Direction Values of Ballista Model, **c)** Displacement of Z-Direction Values of Ballista Model

In both models, the greatest displacement was observed at the buccal apex of the first premolar tooth, the value was 0.000365 mm distally in the Ballista model and 0.000125 mm distally in the Kilroy model. In the Ballista model, the lateral tooth apex moved 0.000198 mm mesially, while in the Kilroy model, the apex of the lateral tooth moved 0.000065 mm palatally (Figures 2b and 3b).

In the Ballista model, the maximum extrusion was 0.0003 mm in the first premolar palatal apex, whereas in the Kilroy model, the maximum extrusion was 0.0002 mm in the lateral tooth apex. An apical intrusion of the central tooth was observed in both models. The intrusion was observed in the lateral tooth apex in the Ballista model, and extrusion was observed in the lateral tooth apex in the Kilroy model (Figures 2c and 3c). Extrusion was observed in the apex of the first premolar in the Ballista model, and an intrusion was observed in the apex of the first premolar in the Kilroy model (Table 1).

When the von Mises stress values on the incisal and cusp tips were compared, the von Mises values were found to be highest in different teeth of the two models (Figures 1a, b) In Ballista model, the highest value was measured at 0.003642 N/mm^2 at the buccal cusp tip of the first premolar tooth, while in the Kilroy model, the highest value was measured at the lateral tooth incisal edge of 0.002989 N/mm^2 (Table 2).

Considering the findings of the impacted canine teeth (Figures 4a, b), the von Mises values were measured as 0.009896 N/mm^2 at the cusp tip and 0.000164 N/mm^2 at the apex in the Ballista model (Table 3). These values were 0.015334 N/mm^2 at the cusp tip and 0.000205 N/mm^2 at the apex in the Kilroy model (Table 3).

Considering von Mises values at the apical, the highest value was measured in the same tooth in both spring designs with the value of 0.023371 N/mm^2 at the buccal apex of the first premolar in Ballista and 0.009941 N/mm^2 at the Kilroy model.

DISCUSSION

Techniques for orthodontic eruption of impacted canines remain a controversial issue.[1] During the orthodontic eruption of the impacted tooth, various force changes occur in both the impacted tooth and the adjacent teeth or their periodontal structures.[23-25]

Although there were some FEM studies related to the eruption of the impacted canine in the literature, no studies examined the stress and displacement values caused by Ballista and Kilroy springs in adjacent teeth and surrounding tissues.[26] Han et al.[27] stated that 0.3-0.4 Newton amount of orthodontic force was needed for extrusion. Bishara[2] stated that this force should be a maximum of 60 g. Nagendraprasad et al.[28] reported that the pressure values that affected the tooth and surrounding tissues showed minimal differences depending on the angle of the impacted tooth in the maxilla when 50 g, 70 g, and 100 g of force were applied, however, the spring design was not mentioned in their study.

Although there was an increase in movement of the impacted teeth when the amount of force increased, a certain value of increase might cause an opposite effect by increasing the tensile pressure in the surrounding tissues. Some studies have reported that pressures higher than 16 kPa (0.016 mPa), which is equal to human systolic pressure, might cause soft tissue necrosis and hyalinization in periodontal ligaments.[29-31] Thus, this study was designed with a sustaining force of 60 g in accordance with the previous literature.[2,26,27]

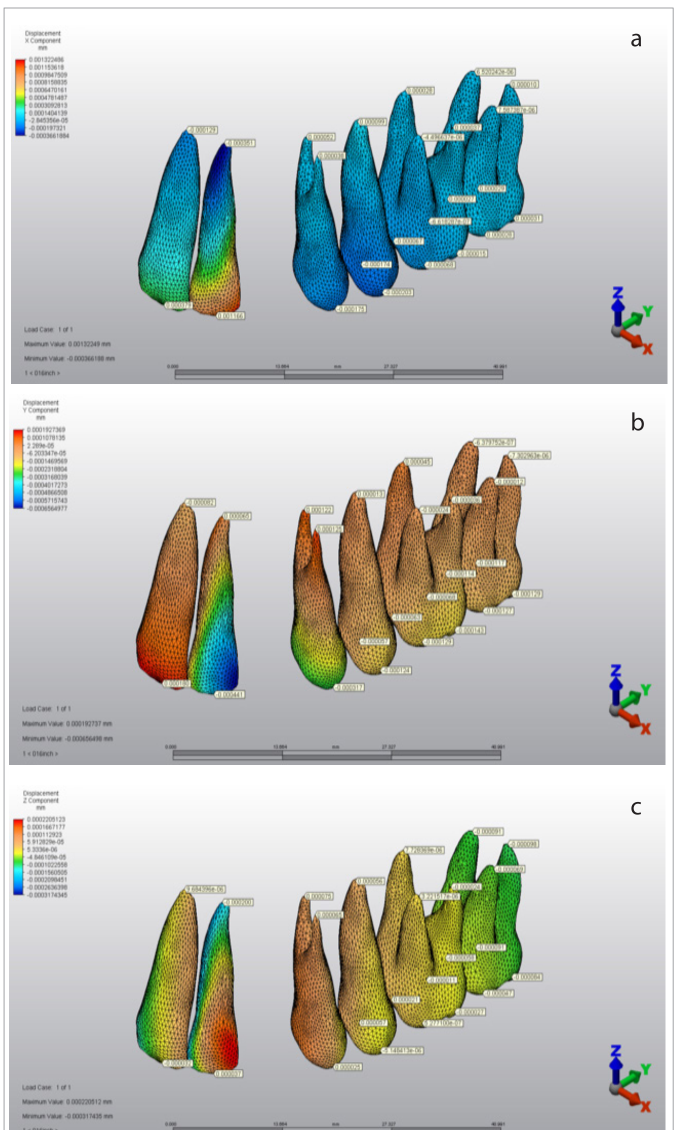

Figure 3. a) Displacement of X-Direction Values of Kilroy Model, **b)** Displacement of Y-Direction Values of Kilroy Model, **c)** Displacement of Z-Direction Values of Kilroy Model

Table 1. Total and X-, Y-, and Z-direction displacement values of the incisal edges, cusp tips, and apices of the adjacent teeth (mm)

	Tooth	Total		X-direction		Y-direction		Z-direction	
		Model 1 Ballista	Model 2 Kilroy	Model 1 Ballista	Model 2 Kilroy	Model 1 Ballista	Model 2 Kilroy	Model 1 Ballista	Model 2 Kilroy
Displacement values of the incisal edges and cusp tips (mm)	Central	0.000494	0.000421	0.000148	0.000379	0.000466	0.00018	-0.000069	-0.000032
	Lateral	0.000656	0.001247	0.000231	0.001166	0.000614	-0.000441	-0.00002	0.000037
	1. Premolar Buccal	0.001065	0.000363	0.000889	-0.00017	-0.00058	-0.000317	0.00007	0.000025
	1. Premolar Palatal	0.001228	0.000392	0.000709	-0.00017	-0.00095	-0.000347	-0.000314	0.000064
Displacement values of the apices (mm)	Central	0.000195	0.000153	-0.000034	-0.000129	-0.000182	-0.000082	0.000058	0.00000968
	Lateral	0.000226	0.000409	-0.000071	-0.000351	-0.000198	0.000065	0.000084	-0.0002
	1. Premolar Buccal	0.000437	0.000146	-0.000233	0.000038	0.000365	0.000125	-0.000056	0.000065
	1. Premolar Palatal	0.000495	0.000152	-0.000319	0.000052	0.00023	0.000122	-0.0003	0.000075

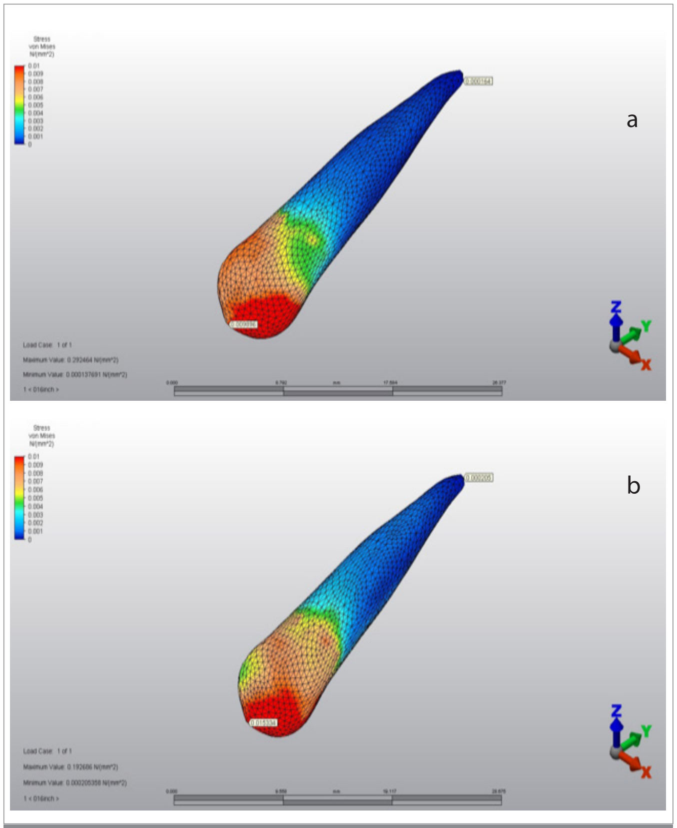

Figure 4. a) von Mises Stress Values at the Impacted Canine of Ballista Model, **b)** von Mises Stress Values at the Impacted Canine of Kilroy Model

In orthodontic forced eruption, to apply a continuous, light and controlled force on palatally impacted canines results in effective tooth movement and may prevent side effects on both the impacted tooth and adjacent teeth. Despite the presence of the same force loading, use of different mechanics creates biomechanical differences. Yadav et al.[23] found that the Kilroy spring showed the most consistent force than that of elastic chain and steel ligature, therefore in this study it was aimed to compare two different kinds of springs.

FEM analysis is often preferred to investigate the force and stress distribution during the eruption of impacted canines because of its advantages, such as simplicity of application, high speed, and repeatability.[26,28,31-33]

The properties of the materials and textures were the most important factors that affected the stress distribution in FEM studies, and the modulus of elasticity of the springs, bone and Poisson ratio was critical distinguishing features.[34] The evaluated structures were assumed to be homogeneous, isotropic, and linearly elastic, and models were made based on this concept. In practical use, it is not possible for any 3D structure or material to be completely homogeneous and isotropic,[34] unlike clinical conditions, which must be treated with caution. The outcomes in clinical conditions may differ depending on the age, bone thickness, quality and complexity of the malocclusion of the patient.[35]

Table 2. Von Mises stress of the incisal edges and cusp tips, and the apices of the adjacent teeth (N/mm^2)

		Model 1 Ballista	Model 2 Kilroy
Von Mises stress of the incisal edges and cusp tips (N/mm^2)	Central	0.000731	0.000591
	Lateral	0.000665	0.002989
	1. Premolar Buccal	0.003642	0.002563
	1. Premolar Palatal	0.002411	0.000670
Von Mises stress of the apices (N/mm^2)	Central	0.004382	0.004652
	Lateral	0.00441	0.008243
	1. Premolar Buccal	0.023371	0.009941
	1. Premolar Palatal	0.017724	0.005327

Table 3. Ballista and Kilroy models total displacement and von Mises stress at the impacted canine

		Cusp Tips	Apex
Ballista Model	Total displacement (mm)	0.000015	0.00000939
	X-direction displacement (mm)	0.0000071	-0.00000345
	Y-direction displacement (mm)	-0.0000013	-0.00000178
	Z-direction displacement (mm)	-0.000013	-0.00000855
	von Mises (N/mm^2)	0.009896	0.000164
Kilroy Model	Total displacement (mm)	0.000017	0.000014
	X-direction displacement (mm)	0.00000647	-0.000003
	Y-direction displacement (mm)	-0.000015	-0.00000664
	Z-direction displacement (mm)	-0.00000497	-0.000012
	von Mises (N/mm^2)	0.015334	0.000205

In this study, 2 simulated models were formed, and the amount of movement of the maxillary teeth in three directions of space and von Mises stress values at adjacent teeth (tooth numbers 21, 22 and 24) and those of the impacted canine were measured. The measured values were similar to the tooth displacement amounts and forces that were reported in previous studies.[26,28,30]

Although the applied forces in the literature were 0.5-2.5 N, Zeno et al.[26] also applied 1 N (100 g) forces in their study, and the lowest stresses were observed under vertical forces. They also found that the average stress value in the impacted canine tooth was 6.41 kPa buccal, 5.97 kPa vertical, and 6.64 kPa distal.[25] In this study, the values at impacted canines were measured as 15.334 kPa in the Kilroy model and 9.89 kPa in the Ballista model, which were higher than those in Zeno et al.[26] and the authors of this study thought that spring designs of Kilroy and Ballista models might be the cause of this difference. Zeno et al.[26] applied 100 g/F in their study, and although the force was 60 g in this study, the higher von Mises values at the tip of the impacted canine tooth cusp were higher. This can be attributed to the technical sensitivity in the model design and spring design, therefore controlled studies are needed in this regard. Also, the resultant stresses in the study were an average of a sample of impacted canines of varying severity, which could explain the difference compared to the current study as the impacted canine model used was possibly of higher severity and therefore resulted in higher stress.

In this study, 0.0002 mm extrusion was observed in the apex of the lateral tooth in the Kilroy model and 0.000084 mm intrusion in the lateral tooth in the Ballista model. Sezici et al.[31] measured more extrusion (0.0885 mm) in the lateral tooth in the Kilroy spring model. The lower displacement of the apex of the lateral tooth in the palatal direction in the Kilroy group showed that the final torque requirement of the impacted tooth was clinically less important when a Kilroy spring was used.

Apical extrusion at the incisal edge of the lateral tooth in the Kilroy model was measured as 0.001247 in this study, whereas Sezici et al.[31] measured the total value as 0.19324 mm. This difference can be attributed to the model design and the difference in the FEM method. Sezici et al.[31] reported that the Kilroy spring design caused a more mesial displacement in the lateral teeth than the Niti coil spring design. The authors also reported buccal movement in the lateral and premolar teeth.[31] When the X-direction displacement was examined, the mesial movement was the largest in the lateral tooth in Kilroy.

In this study, the von Mises stress value of the incisal edge of the lateral tooth was 0.002989 MPa, while the total value for the lateral tooth was 0.00529 MPa in a similar study.[31] The value for the premolar tooth in this study (0.002563 MPa) was lower than that in the previous report (0.00641 MPa).[31]

In this study, the two spring designs showed higher von Mises values in different teeth. In the Ballista model, the highest value was measured at the buccal tip of the first premolar tooth, while in the Kilroy model, the highest value was measured at the incisal edge of the lateral tooth and the values were compatible with the literature.[31]

The displacement value of the tip of the impacted canine was close to the reported value of Nagendraprasad et al.[28] in this study the highest stress value was recorded around the impacted canine in Kilroy model like a previous report,[31] in which the same kind of spring was used.

When the position of the impacted tooth changed in three directions of space, the movement patterns occurring in the mesial, buccal, and occlusal plane directions, were compatible with the literature.[28] In this study, the most displacement was detected at the incisal edge of tooth number 2.2 in the Kilroy model and at the palatal cusp tip of tooth number 2.4 in the Ballista model.

Shastri et al.[36] used a model of erupting impacted canine teeth with a modified K-9 spring to eliminate side effects in adjacent teeth. For this purpose, the authors applied a buccal crown torque to the posterior teeth and stated that they also protected periodontal health by reducing the tipping of the teeth.[35] In this study the greater buccal movement was seen in tooth 2.2 in Kilroy model, theoretically it can be thought that a need for palatal crown torque may arise when Kilroy springs are used.

In this study, the von Mises stress value measured in the impacted canine of the Ballista model was also compatible with the literature.[26,30] Comparing the Kilroy model and the Niti coil, Sezici et al.[31] reported that the von Mises stress values in the impacted canine tooth in the Kilroy models (60 g) were very similar to the results observed in this study.

The differences in the number of nodes, model designs, and forces used in FEM studies can explain the differences between the previous reports in the literature.[26,29,31]

When evaluating the possible shortcomings of this study, the limitations of the FEM compared with clinical methods should be discussed first. Meanwhile, performing such mechanical studies under clinical conditions also poses serious difficulties due to patient-related variables.

Another possible limitation of this study was that the canine teeth were analyzed assuming that they were in a fixed position in all 3 planes and all models. When the position of the impacted canine becomes horizontal, the required force changes, and accordingly, the location and degree of stress on the tooth and surrounding tissues can vary, therefore more studies are required on this issue.

CONCLUSION

The null hypothesis was rejected. The von Mises stress values were higher in the Kilroy model at the cusp tip and the apical part of the impacted tooth than in the Ballista model. The von Mises values of lateral tooth measured in the Kilroy spring model were higher than those of the Ballista model. The highest von Mises stress values were concentrated in the buccal root apex of the first premolar tooth in both models, and the Ballista model had higher stress values than that of the Kilroy model.

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Ethics

Ethics Committee Approval: This study was approved by the Istanbul Medipol University Clinical Research Ethics Committee (Approval number: 10840098-604.01.01-E.8437).

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - N.K.A.; Design - N.K.A.; Supervision - G.S., N.K.A.; Materials - E.N.B., N.K.A.; Analysis and/or Interpretation - G.S., E.N.B., N.K.A.; Literature Review - E.N.B., N.K.A.; Writing - G.S., E.N.B, N.K.A.; Critical Review: G.S., N.K.A.

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TURKISH JOURNAL of ORTHODONTICS

Original Article

How Similar are the Dentoskeletal Characteristics of Class III Double-Jaw Surgery Patients with Ideal Post-Treatment Profiles and Class I Subjects?

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Main Points

- The maxilla and soft -tissue chin were protrusive in Class III double-jaw surgery patients with ideal final soft-tissue profiles compared with skeletally harmonious subjects.
- Soft-tissues masked one-third of the maxillary and one-fourth of the mandibular surgical correction.
- Although the mandibular incisors were slightly compensated before surgery and further retroclined at the post-surgical phase, the soft-tissue outcome was not adversely affected.

ABSTRACT

Objective: To define the dental and skeletal characteristics of Class III surgery patients with ideal final soft-tissue profiles, and to compare them with those of Class I subjects. Also, to show how soft-tissues respond to surgical jaw movements and contribute to the outcome.

Methods: This short-term, retrospective study was conducted using pre-treatment (T0), pre-surgery (T1), and post-treatment (T2) records of 50 double-jaw Class III surgery patients who presented with ideal cephalometric characteristics in sagittal (Holdaway and soft-tissue convexity angles) and vertical dimensions (GoGn. SN angle and upper-to-lower face harmony) at the end of treatment, and 50 control subjects.

Results: At T2, the horizontal distance between the vertical reference plane (a perpendicular plane to the horizontal reference plane that is angulated 7° clockwise to the SN plane) and hard-tissue A, B and Pog points, lower lip, soft-tissue B, and pogonion points were greater, Wits appraisal was more negative, U1.PP was higher, IMPA was lower, and soft-tissue chin (Pog-Pog') was thicker in Group 1 when compared to Group 2 ($p<0.05$). Moreover, upper lip and subnasal (A-A') thicknesses were decreased, and chin thickness (Pog-Pog') was increased significantly ($p<0.05$).

Conclusion: Dentoskeletal characteristics of an ideally-treated Class III surgery patient differed from a Class I subject concerning a protrusive maxilla and soft-tissue pogonion, and incisors that were not fully-decompensated. Soft-tissues hindered the actual surgical correction to 66% and 73% in the mid- and lower-faces, respectively.

Keywords: Orthognathic surgery, skeletal Class III, surgical treatment, soft-tissue response

INTRODUCTION

Craniofacial growth in Class III patients differs from Class I subjects with regard to the anatomical differences at the cranial base where the maxilla is attached to and the glenoid fossa where the mandible articulates, the intrinsic growth potentials of the maxilla and mandible, and genetic and environmental factors affecting the growth of the nasal cartilage and condyles. These factors play important roles in the spatial and morphologic features of the jaws.[1-3] Moreover, thickness, mobility, and tonicity of the soft-tissues change with the functional needs of the patient and alter the contraction patterns of the facial muscles.[4] In addition to the dissimilarities in the hard- and soft-tissues, changes in the maxillary and mandibular incisor inclinations to conceal the underlying

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skeletal discrepancy further differentiate these individuals from one another.[5]

Orthognathic surgery can be considered the art of medical architecture that resculpts the dentoskeletal infrastructure of the face toward a more esthetic and functional state. The norms leading to an esthetic appearance are well-defined in the literature; however, the way to achieve it from skeletal and dental perspectives is highly singular. For a few decades now, orthodontists and maxillofacial surgeons have been using cephalometric prediction software to plan the final positions of the jaws while seeing the predicted outcome simultaneously. However, some anatomical factors, such as soft-tissue response or the original contours of the hard-tissues, introduce uncertainty to the predicted surgical outcome; therefore, it is important to apprehend inherent differences between skeletally harmonious and surgically-treated Class III subjects to set realistic goals.[6-8] Previous studies have shown drastic improvement in Class III facial profile with surgical-treatment, and analyzed soft-tissue response and its contribution to the final outcome.[4,9-12] The results of these studies demonstrated that soft-tissues covering the maxillary structures were less responsive than those covering the mandible, and mandible and lower lip were dominantly responsible for the improvement in the profile. However, the similarities of hard- and soft-tissue characteristics between surgically-treated Class III patients and Class I subjects are seldom studied.

Therefore, the aims of this study were: (1) to define dental and skeletal features beneath an ideally-treated Class III surgery patient, and compare these with skeletally harmonious control subjects, and (2) to show how soft-tissues respond to surgical jaw movements and contribute to the outcome.

METHODS

Formal approval from the Institutional Review Board of Başkent University (project no: D-KA22/24, date: 17.05.2022) was obtained, and the study was conducted protecting rights and interests of the research participants. Sample size calculation based on the difference in SNA-angle between skeletally Class I and Class III subjects, as shown in the study by Guyer et al.[13] showed that 50 subjects were needed in each group to reach 95% power with 5% Type I error (SPSS for Windows 22.0, SPSS Inc, Illinois, USA).

This retrospective study included orthodontic records of 50 ideally-treated orthognathic surgery patients who underwent double-jaw surgery for correcting skeletal Class III malocclusion (Group 1), and 50 control subjects (Group 2), all of whom were of European descent. Inclusion criteria for Group 1 were patients who (1) had ideal soft-tissue profiles at the end of treatment according to both Holdaway (N'-Pog'-UL, 7º-14º) and soft-tissue convexity angles (Gl'-Pronasale-Pog', 128.4º-136.4º), and (2) were normodivergent according to GoGn. SN angle (26º-38º) and upper-to-lower face harmony (Gl'-Sn:Sn-Me') (93.5%-103.5%) at the beginning of treatment, and (3) were fully decompensated before surgery, i.e., who were not treated with surgery-first or surgery-modified approaches. Exclusion criteria were patients (1) who had severe asymmetry, (2) presenting craniofacial syndromes, and (3) who had undergone major (rhinoplasty, etc.) or minor surgeries (filler injections, etc.) of the maxillofacial region during treatment, other than orthognathic surgery. A sex- and age-matched control group (Group 2), who presented dental and skeletal Class I malocclusion with minor incisor crowding, and whose Holdaway and soft-tissue convexity angles, as well as GoGn. SN angle and upper-to-lower face harmony values were within the normal range was studied for intergroup comparisons.

Lateral cephalometric radiographs taken at the beginning of treatment (T0), before surgery (T1) and at the end of treatment (on the debonding session) (T2) for Group 1, and at T0 for Group 2 were digitally traced and analyzed using Dolphin Imaging software (Vers 11.5 Premium, Patterson Dental, CA, USA). By the time of debonding in Group 1, soft-tissues had already recovered from surgery-induced edema. A total of 29 cephalometric variables were measured by the same investigator (Figure 1).

Three weeks after the initial data assessment, randomly chosen cephalometric radiographs of 10 patients from each group were re-traced by the same investigator for intraexaminer reliability.

Statistical Analysis

Statistical analyses were performed using the SPSS software package (SPSS for Windows 22.0, SPSS Inc, Illinois, USA). As the data were not normally-distributed, Mann-Whitney U and Wilcoxon signed-rank tests were used to compare differences between and within groups. The level of significance was set at $p<0.05$.

Intraclass correlation coefficients calculated to assess intraexaminer reliability ranged between 0.901 and 0.986.

RESULTS

Mean age at the beginning of treatment in Group 1 was 21.1 ± 4 years [minimum-maximum (min.-max.), 15.6-32.3 years], and Group 2 was 21.8 ± 4.2 years (min.-max., 15.7-33.3 years). Both groups comprised 27 female and 22 male patients. Patients in both groups were either at the R_U stage according to hand-and-wrist films[14], or at the 5th or 6th stage according to the cervical vertebral maturation method[15].

Cephalometric parameters are compared between the groups, and the results are presented in Table 1. Parameters that were similar between the groups at T0 were A-VRP (mm), PP.SN (º), occlusal plane. SN (º), overbite (mm), lower lip thickness (mm), and B-B' (mm). Parameters that were similar between the groups at T1 were U1-NA (mm), U1.PP (º), and L1.NB (º).

Parameters that showed significant differences between the surgery group at T2 and the control group were as follows: hard-tissue A point, hard- and soft-tissue B and Pog points, and

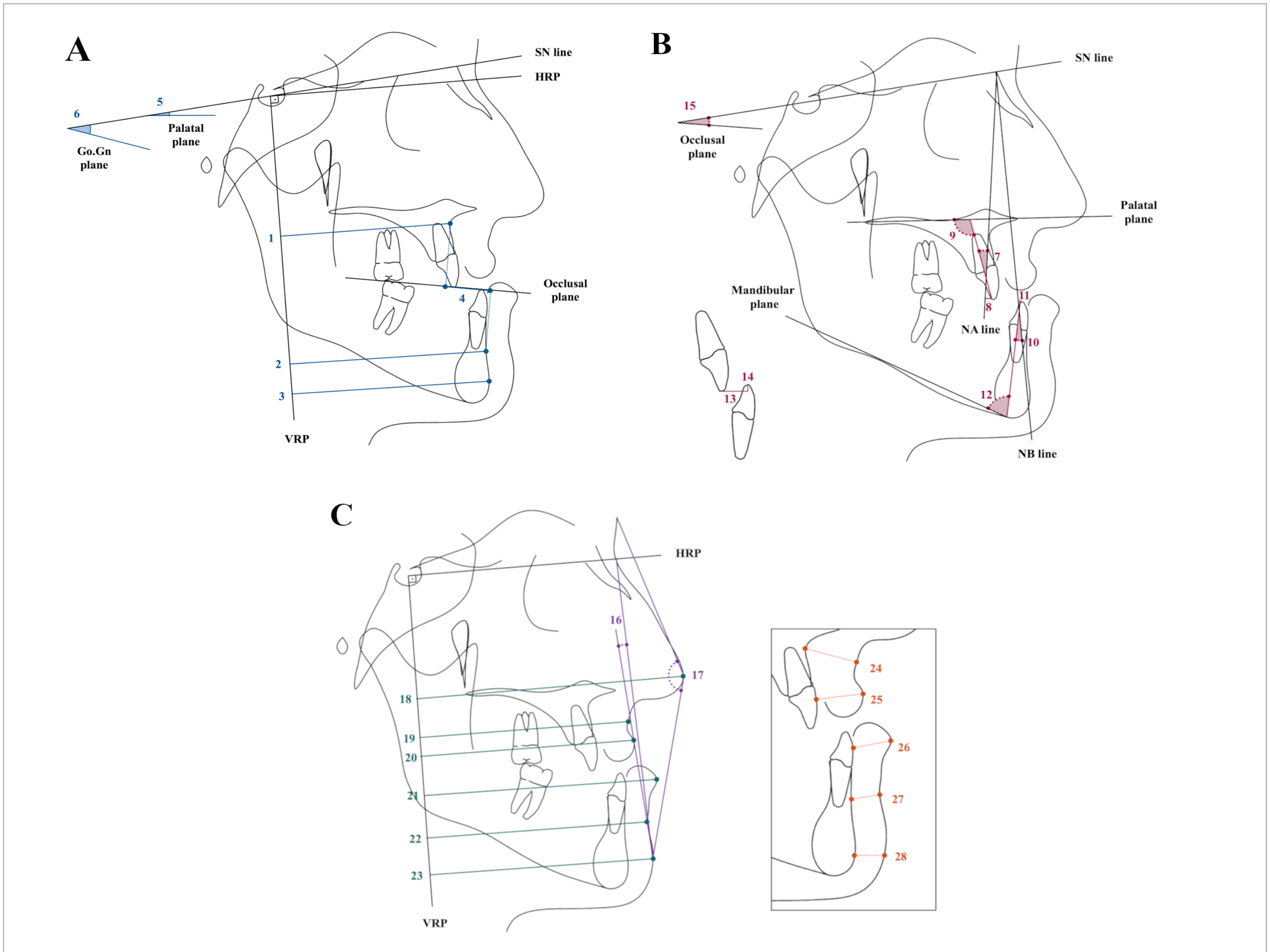

Figure 1. Reference planes and cephalometric variables used in the study. Reference planes; SN (Sella-Nasion) line; Horizontal reference plane (HRP), horizontal plane angulated 7° clockwise to the SN plane at Sella; Vertical reference plane (VRP), perpendicular plane to the HRP passing through Sella; Palatal (ANS-PNS) plane (PP); Occlusal plane, passing through mesiobuccal cusp tips of the first molars and incisal edges of the central incisors; NA line; NB line; Mandibular (Go-Me) plane. Cephalometric variables; **A,** 1, A-VRP; 2, B-VRP; 3, Pog-VRP; 4, Wits appraisal; 5, SN.PP; 6, Go.Gn.SN; **B,** 7; U1.NA; 8, U1-NA; 9, U1.PP; 10, L1.NB; 11, L1-NB; 12, IMPA; 13, Overjet; 14, Overbite; 15. Occlusal plane.SN; **C,** 16, Holdaway angle (N'-Pog'-UL); 17, Soft-tissue convexity angle (Gl'-Pronasale-Pog'); 18, Pronasale-VRP; 19, A'-VRP; 20, Upper lip-VRP; 21, Lower lip-VRP; 22, B'-VRP; 23, Pog'-VRP; 24, Subnasal thickness (A-A'); 25, Upper lip thickness; 26, Lower lip thickness; 27, Suprachin thickness (B-B'); 28, Chin thickness (Pog-Pog')

lower lip were more protruded, and soft-tissue chin (Pog-Pog') was thicker in Group 1. Furthermore, Wits appraisal was more negative, U1.PP (°) was higher and IMPA (°) was lower in Group 1 compared to Group 2.

Table 2 presents the amount and significance of changes in Group 1 between T1-T0 and T2-T1. The amount of advancement at the A point was 3.8 mm, whereas the amount of setback at the B and Pog points were 4.6 and 5.9, respectively. Maxillary incisors were retroclined for 2.7° and then proclined for 2.9° between T1-T0 and T2-T1, respectively. Mandibular incisors, on the other hand, were proclined for 12.2° between T1-T0 and then retroclined for 4.7° between T2-T1. Overjet was decreased by 3.7 mm between T1-T0 and then increased by 9.6 mm between T2-T1. Inclinations of both the palatal and occlusal planes relative to the SN plane increased. Soft-tissue parameters Holdaway and soft-tissue convexity angles improved toward a more convex profile between T2-T1. Pronasale, A' point, and upper lip moved anteriorly, while the lower lip, B' and Pog' points moved posteriorly between T2-T1, all of which were statistically significant. Meanwhile, upper lip thickness and A-A' decreased, and Pog-Pog' increased significantly between T2-T1.

DISCUSSION

This study was conducted to investigate the dental and skeletal components of an esthetically pleasing soft-tissue profile achieved with double-jaw surgery in Class III patients, and to compare them with normal values acquired from skeletally harmonious subjects, while studying the effects of soft-tissues on the outcome. To do so, Class III surgery patients with ideal final soft-tissue profiles were selected from our university archive, and dentoskeletal characteristics were studied at 3 timepoints. A sex- and age-matched control group with the same ethnic origin was further identified to obtain reference

Table 1. Intergroup comparisons between the control (C) and orthognathic surgery (OS) groups at the beginning of treatment (T0), before surgery (T1) and at the end of treatment (T2) by Mann-Whitney U test

	Control (C) (n=49)	Orthognathic surgery (OS) (n=49)			Between groups		
	T0	T0	T1	T2	C & OS T0	C & OS T1	C & OS T2
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	p value	p value	p value
Skeletal							
A - VRP (mm)	63.5 ± 3.9	62.2 ± 4.2	62.2 ± 4.3	66 ± 3.9	0.305	0.315	**0.013***
B - VRP (mm)	58.2 ± 4.7	68.2 ± 5.4	67.8 ± 4.8	63.3 ± 4.4	**0.0001***	**0.0001***	**0.0001***
Pog - VRP (mm)	61.7 ± 4.6	70.9 ± 3.9	69.7 ± 4.1	63.9 ± 3.8	**0.001***	**0.001***	**0.01***
Wits appraisal (mm)	-0.4 ± 2.6	-11 ± 4	-12.4 ± 3	-3.6 ± 2.5	**0.0001***	**0.0001***	**0.0001***
GoGn. SN (º)	32 ± 3	32.7 ± 3.8	33.2 ± 3.6	33.4 ± 3.2	0.256	0.077	0.053
SN . PP (º)	7.8 ± 3.1	7.5 ± 3.9	7.4 ± 4.1	10.7 ± 4.1	0.909	0.529	0.196
Dental							
U1 . NA (º)	25 ± 6.2	30.1 ± 6.7	27.4 ± 6.7	27.1 ± 6.6	**0.0001***	**0.048***	**0.048***
U1 - NA (mm)	4.9 ± 2.2	7.2 ± 2.5	5.7 ± 2.6	4.8 ± 2.1	**0.0001***	0.058	0.924
U1 . PP (º)	113.6 ± 6.9	116.5 ± 6.7	113.8 ± 8.2	116.7 ± 7.1	**0.043***	0.665	**0.016***
L1 . NB (º)	25.7 ± 4.7	16.1 ± 6.8	27.3 ± 5.7	21.5 ± 5.5	**0.001***	0.091	**0.0001***
L1 - NB (mm)	4.9 ± 1.7	2.9 ± 2.2	5.6 ± 1.8	4.4 ± 1.7	**0.0001***	**0.045***	0.208
IMPA (º)	92.8 ± 5.6	75.8 ± 7.6	88 ± 5.8	83.2 ± 6.6	**0.0001***	**0.0001***	**0.0001***
Overjet (mm)	3 ± 1.2	-2.9 ± 2.7	-6.6 ± 2.4	3 ± 0.7	**0.0001***	**0.0001***	0.784
Overbite (mm)	1.3 ± 1.9	0.9 ± 2.7	0.9 ± 1.8	1.7 ± 0.6	0.332	0.131	0.161
Occlusal plane SN (º)	15.4 ± 4	13.9 ± 4.1	16.4 ± 3.9	19.2 ± 3.4	0.071	0.386	0.443
Soft tissue							
Holdaway angle (º)	12.2 ± 2	4.9 ± 3.6	4.5 ± 3.3	11 ± 2.3	**0.0001***	**0.0001***	0.443
Soft tissue convexity angle (º)	130.5 ± 3	139.3 ± 4.9	139.4 ± 4.9	132 ± 4.3	**0.0001***	**0.0001***	0.567
G'-Sn : Sn-Me' (%)	98.6 ± 8.9	95.5 ± 7.9	94.6 ± 8.1	93.7 ± 7.9	0.189	0.079	0.067
Pronasale - VRP (mm)	95 ± 6.4	93.1 ± 5.9	93 ± 5.9	94.1 ± 5.7	**0.001***	**0.001***	0.143
A' - VRP (mm)	76.2 ± 5.9	74.7 ± 5.7	73.5 ± 5.4	76 ± 5.6	**0.001***	**0.001***	0.143
UL - VRP (mm)	79.8 ± 6.5	78.4 ± 6.1	77.8 ± 6.2	79.8 ± 5.6	**0.001***	**0.001***	0.147
LL - VRP (mm)	76.9 ± 7.2	84.1 ± 7	85 ± 7.3	81 ± 6.3	**0.0001***	**0.0001***	**0.003***
B' - VRP (mm)	74.3 ± 6.9	83.2 ± 7.4	82.2 ± 7.6	77.7 ± 7.6	**0.0001***	**0.0001***	**0.001***
Pog' - VRP (mm)	71.2 ± 8	81.4 ± 8.2	80.8 ± 8.3	76.5 ± 7.2	**0.0001***	**0.0001***	**0.001***
A - A' (mm)	15.6 ± 2.1	16.7 ± 2	16.3 ± 1.8	14.9 ± 1.5	**0.014***	**0.041***	0.149
UL thickness (mm)	13.9 ± 2.1	16 ± 2.7	16.7 ± 2.3	14.3 ± 1.8	**0.0001***	**0.0001***	0.275
LL thickness (mm)	14.8 ± 1.4	14 ± 1.7	14.3 ± 1.7	14.2 ± 1.7	0.471	0.789	0.563
B - B' (mm)	11.5 ± 1.8	11.2 ± 1.3	11.1 ± 1.6	11.2 ± 1.4	0.994	0.327	0.765
Pog - Pog' (mm)	10.3 ± 2.3	13.1 ± 2.2	13 ± 2.1	14.4 ± 2.2	**0.014***	**0.001***	**0.001***

*$p<0.05$; HRP, horizontal reference plane; LL, lower lip; PP, palatal plane; SD, standard deviation; SN, Sella-Nasion line; UL, upper lip; VRP, vertical reference plane

values for comparisons. Soft-tissue profile was screened using two different parameters: Holdaway (N'-Pog'-UL) and soft-tissue convexity angles (Gl'-Pronasale-Pog'), and expected to be ideal according to both. The reason for using these particular parameters can be explained with the fact that they focus on key landmarks that define profile esthetics (Pog' & UL, Pog' & Pronasale) with respect to stable reference points (N'and Gl'). Furthermore, patients with a normodivergent facial type were preferred to investigate sagittal changes without being diminished or exaggerated by vertical and/or rotational jaw movements, and to eliminate the effect of increased vertical growth on the morphology of the maxilla.

Cephalometric parameters in surgery patients deviate acutely from ideal values and tend to approximate to the norms after surgical treatment. As opposed to this, although the horizontal distance of hard-tissue A point to VRP (A-VRP) was similar to that of the control group, the maxilla had to be advanced for 3.8 mm, and its final position was beyond the upper limit of the normal range. However, the soft-tissue profile was rather esthetically

Table 2. Comparison of the changes in the orthognathic surgery group before surgery (T1-T0) and after surgery (T2-T1) by Wilcoxon signed-rank test

	T0	T1	T2	T1-T0		T2-T1	
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	p value	Mean ± SD	p value
Skeletal							
A - VRP (mm)	62.2 ± 4.2	62.2 ± 4.3	66 ± 3.9	0 ± 0.4	0.865	3.8 ± 2	**0.0001***
B - VRP (mm)	68.2 ± 5.4	67.8 ± 4.8	63.3 ± 4.4	-0.4 ± 0.9	0.237	-4.6 ± 3	**0.0001***
Pog - VRP (mm)	70.9 ± 3.9	69.7 ± 4.1	63.9 ± 3.8	-1.3 ± 1.1	0.089	-5.9 ± 2.7	**0.0001***
Wits appraisal (mm)	-11 ± 4	-12.4 ± 3	-3.6 ± 2.5	-1.4 ± 2.1	0.059	8.8 ± 2.7	**0.0001***
GoGn . SN (°)	32.7 ± 3.8	33.2 ± 3.6	33.4 ± 3.2	0.5 ± 2.8	0.197	0.2 ± 3.4	0.641
PP . SN (°)	7.5 ± 3.9	7.4 ± 4.1	10.7 ± 4.1	-0.2 ± 1.1	0.897	3.3 ± 2.6	**0.003***
Dental							
U1 . NA (°)	30.1 ± 6.7	27.4 ± 6.7	25.6 ± 6.6	-2.7 ± 3.2	**0.008***	-1.8 ± 6	**0.039***
U1 - NA (mm)	7.2 ± 2.5	5.7 ± 2.6	4.8 ± 2.1	-1.5 ± 2.3	**0.0001***	-0.9 ± 2	**0.002***
U1 . PP (°)	116.5 ± 6.7	113.8 ± 8.2	116.7 ± 7.1	-2.7 ± 3.1	**0.01***	2.9 ± 5.7	**0.002***
L1 . NB (°)	16.1 ± 6.8	27.3 ± 5.7	21.5 ± 5.5	11.3 ± 7.7	**0.0001***	-5.8 ± 4.9	**0.0001***
L1 - NB (mm)	2.9 ± 2.2	5.6 ± 1.8	4.4 ± 1.7	2.7 ± 1.7	**0.0001***	-1.2 ± 1.2	**0.0001***
IMPA (°)	75.8 ± 7.6	88 ± 5.8	83.2 ± 6.6	12.2 ± 6.9	**0.0001***	-4.7 ± 4.4	**0.0001***
Overjet (mm)	-2.9 ± 2.7	-6.6 ± 2.4	3 ± 0.7	-3.7 ± 2.2	**0.0001***	9.6 ± 2.4	**0.0001***
Overbite (mm)	0.9 ± 2.7	0.9 ± 1.8	1.7 ± 0.6	0 ± 2.2	0.728	0.8 ± 1.7	**0.003***
Occ plane . SN (°)	13.9 ± 4.1	15.4 ± 3.9	19.2 ± 3.4	1.6 ± 3	**0.0001***	3.8 ± 3.2	**0.0001***
Soft tissue							
Holdaway angle (°)	4.9 ± 3.6	4.5 ± 3.3	11 ± 2.3	-0.4 ± 2.3	0.162	6.5 ± 2.7	**0.0001***
Soft tissue convexity angle (°)	139.3 ± 4.9	139.4 ± 4.9	132 ± 4.3	0.1 ± 2.5	0.98	-7.4 ± 2.7	**0.0001***
G'-Sn : Sn-Me' (%)	95.5 ± 7.9	94.6 ± 8.1	93.7 ± 7.9	-0.9 ± 5.5	0.124	-0.9 ± 7.2	0.456
Tip of nose - VRP (mm)	93.1 ± 5.9	93 ± 5.9	94.1 ± 5.7	-0.1 ± 1.1	0.787	1 ± 1.4	**0.0001***
A' - VRP (mm)	74.7 ± 5.7	73.5 ± 5.4	76 ± 5.6	-1.1 ± 1.1	**0.001***	2.5 ± 1.1	**0.0001***
UL - VRP (mm)	78.4 ± 6.1	77.8 ± 6.2	79.8 ± 5.6	-0.6 ± 1.9	**0.017***	2 ± 2.4	**0.0001***
LL - VRP (mm)	84.1 ± 7	85 ± 7.3	81 ± 6.3	0.9 ± 2	**0.003***	-4 ± 2.8	**0.0001***
B' - VRP (mm)	83.2 ± 7.4	82.2 ± 7.6	77.7 ± 7.6	-0.9 ± 1.1	**0.01***	-4.5 ± 2.3	**0.0001***
Pog' - VRP (mm)	81.4 ± 8.2	80.8 ± 8.3	76.5 ± 7.2	-0.7 ± 1.8	**0.02***	-4.3 ± 3.5	**0.0001***
A - A' (mm)	16.7 ± 2	16.3 ± 1.8	14.9 ± 1.5	-0.3 ± 1.2	0.079	-1.4 ± 1.4	**0.0001***
UL thickness (mm)	16 ± 2.7	16.7 ± 2.3	14.3 ± 1.8	0.7 ± 3.1	0.281	-2.4 ± 1.5	**0.0001***
LL thickness (mm)	14 ± 1.7	14.3 ± 1.7	14.2 ± 1.7	0.3 ± 1.6	0.131	-0.1 ± 1.6	0.568
B - B' (mm)	11.2 ± 1.3	11.1 ± 1.6	11.2 ± 1.4	-0.1 ± 1.1	0.596	0.1 ± 0.9	0.325
Pog - Pog' (mm)	13.1 ± 2.2	13 ± 2.1	14.4 ± 2.2	-0.2 ± 1.2	0.315	1.5 ± 1.2	**0.0001***

*p<0.05; HRP, horizontal reference plane; LL, lower lip; PP, palatal plane; SD, standard deviation; SN, Sella-Nasion line; UL, upper lip; VRP, vertical reference plane

pleasing at the end of the treatment, but not over-convex. This finding indicates that there may be morphological differences between the anterior contours of ideally-grown and skeletally-deficient maxillae, the latter being flat and lacking curvature to provide enough fullness. Bearing in mind that maxillary advancement may not fully address the mid-facial deficiency, adjunctive procedures to augment the mid-face such as fat grafts, dermal fillers, or implants can also be included in the treatment plan. However, a treatment strategy involving more maxillary advancement and less mandibular set-back is advantageous in obtaining a well-supported mid-face that seems more defined and youthful, as well as reducing submandibular sagging.[16] Furthermore, as the volume of the functioning spaces is characterized by metabolic and functional demands of the body, the risk of relapse can be reduced effectively by preserving the airway volume and tongue space.[17-19]

Soft-tissue characteristics and response against surgical jaw movements is another critical determinant of the outcome, because they may diminish the amount of skeletal correction either by compression and thinning or by relaxation and thickening.[9,10,12] As the original thickness and tonicity of the soft-tissues determine how closely they will follow the hard tissues, pretreatment soft-tissue thicknesses were also studied for comparison.[20,21] According to our results, pretreatment (T0) subnasal (A-A') and upper lip thicknesses, as well as, chin thickness (Pog-Pog′) were thicker in the surgery group; yet, lower lip and suprachin (B-B′) thicknesses were similar between the groups. Furthermore, between T2-T1, subnasal (A-A′) and upper lip thicknesses tended to decrease with maxillary advancement, while soft-tissue chin thickness increased, and lower lip and suprachin thicknesses remained stable after mandibular surgery.

In the maxilla, the ratio of soft to hard tissue changes was 66%, which means that a critical one-third of the maxillary advancement was lost with thinning of the soft-tissues. In line with this finding, many studies have shown that soft-tissue response was weaker in the maxilla compared to the mandible after surgery.[4,10,11] This can be explained with the resection of the anterior nasal spine during surgery and the incision scars limiting upper lip movement,[9-12] but also with the dead space between the maxillary incisors and the upper lip that delays upper lip movement until this gap is filled with maxillary advancement.[20]

The sagittal position of the chin in the surgery group was never similar to that of the control group, and, although statistically insignificant, soft-tissue profile at the end of treatment was less convex in this group. This can be explained with a lesser need for mandibular set-back because of more maxillary advancement, and with the response of soft-tissues covering the lower face. As opposed to the maxilla, the mandibular soft-tissues became thicker as the mandible was set back, which manifested itself as 1.5 mm increase in the chin thickness (Pog-Pog′). The ratio of soft to hard tissue changes was 73%, showing that almost one-fourth of the mandibular set-back did not project on the final soft-tissue profile. This finding is in general agreement with the studies of Chew[11] and Altug-Atac et al.[12].

Mandibular incisors were slightly compensated, yet significantly different from the control group before surgery (T1). They further retroclined during the post-surgical treatment phase (T2-T1) and lost approximately 40% of the decompensatory proclination. This finding is in agreement with the previous studies that have shown that dental relapse was positively correlated with the amount of tooth movement.[22,23] However, even though mandibular incisors were retroclined (83.2° ± 6.6°) compared to the Class I subjects (92.8° ± 5.6°), the soft-tissue profile and sagittal position of the lower lip were ideal at the end of treatment.

Study Limitations

This study was conducted on 2-dimensional data. Blinding was impossible for data collection; however, the data assessor was blinde; therefore, detection bias can be considered low.

CONCLUSION

Class III surgery patients with an ideal post-treatment soft-tissue profile differed from Class I subjects with a protrusive maxilla and a prominent soft-tissue pogonion.

Soft-tissues responded to the surgical jaw movements in a counter-active manner and diminished the actual surgical correction, which may have clinical implications when planning the new positions of the jaws. The decrease in the upper lip and increase in the chin thicknesses led to the loss of one-third and one-fourth of the surgical correction in the mid- and lower-faces, respectively.

Mandibular incisors were slightly compensated before surgery, and further lost a marked amount of decompensatory proclination after surgery without adversely affecting the outcome.

Ethics

Ethics Committee Approval: This study was approved by the Institutional Review Board of Başkent University (project no: D-KA22/24, date: 17.05.2022).

Informed Consent: The study was conducted protecting rights and interests of the research participants.

Peer-review: Externally and internally peer-reviewed.

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Original Article

The Effects of Eucalyptus Oil, Glutathione, and Lemon Essential Oil on the Debonding Force, Adhesive Remnant Index, and Enamel Surface During Debonding of Ceramic Brackets

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Main Points

- Ceramic bracket debonding is facilitated by immersing teeth bonded with them in glutathione for 10 minutes.
- There was no adhesive left behind on teeth treated with glutathione, thus exposing a clear enamel surface- exhibiting peel-off effect.
- Glutathione exhibited superior debonding effects, followed by eucalyptus oil and lemon essential oil.
- A clinically viable option of using a customized tray with glutathione, similar to tooth bleaching trays, to facilitate debonding of ceramic brackets is very much possible in the near future given the reduced immersion time of just ten minutes.

ABSTRACT

Objective: The present study aimed to find a chemical reagent that would reduce the debonding force to enable easier debonding of the ceramic brackets, thus reducing enamel damage as well as chair side time.

Methods: The study included 4 groups -control (distilled water), eucalyptus oil, glutathione and lemon essential oil for immersing teeth bonded with ceramic brackets. Samples (25 in each group), extracted first premolars, were mounted and immersed in their respective solution for a duration of 10 minutes following which they were tested to evaluate the debonding force using the INSTRON universal testing machine. The amount of adhesive left behind on the enamel surface was evaluated using adhesive remnant index (ARI) score and surface changes were checked using a scanning electron microscope.

Results: Teeth immersed in glutathione showed the greatest amount of reduction in debonding force (p=0.001) compared with other groups. ARI scores were low for specimens immersed in glutathione. SEM images showed that teeth in the glutathione group had a cleaner enamel surface, suggesting less or no adhesive was left behind and no sign of enamel damage after debonding ceramic brackets.

Conclusion: Specimens that were immersed in glutathione for a duration of 10 minutes before debonding of ceramic brackets showed the greatest reduction in debonding force compared with control and demonstrated peel off effect with no enamel damage. Glutathione can be used as an effective reagent during the clinical debonding of ceramic brackets.

Keywords: Debonding force, adhesive remnant index, ceramic brackets, eucalyptus essential oil, glutathione, lemon essential oil, peel off effect

INTRODUCTION

Ceramic brackets were introduced in clinical orthodontics to meet the increased demand for an aesthetic appliance and currently are clear alternatives to stainless steel brackets.[1,2] Despite the superior aesthetic advantage, clinicians are faced with challenges associated with increased bond strength and low fracture resistance while debonding, like enamel tear outs, pain, bracket failures, bracket fractures and cracks.[3,4] A systematic review and meta-analysis

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conducted to evaluate enamel micro cracks revealed that debonding was associated with increase in the number, length and width of enamel micro cracks irrespective of brackets.[5] A quantitative analysis of enamel loss during debonding of monocrystalline and polycrystalline ceramic brackets revealed that there was loss of 33µ and 21µ and post -clean-up loss of 18µ and 28µ of enamel respectively. Monocrystalline ceramic brackets left behind most of the adhesive while polycrystalline brackets fractured during debonding and fragments of brackets were left behind along with remnants of adhesive.[6]

Several techniques have been used to overcome the problems encountered during debonding of ceramic brackets like mechanical, ultrasonic, electro-thermal and lasers debonding.[7-10] The use of ultrasonic waves for debonding ceramic brackets can be advantageous over conventional methods in that bracket-adhesive interface is subjected to vibrations but the duration is significantly greater and may be uncomfortable for the patients.[11]

Electrothermal debonding (ETD) focuses on softening of the adhesive material leading to bracket removal with minimal force.[12,13] Laser-aided debonding of ceramic brackets is conceptually similar to electro-thermal approach and works by effectively controlling the thermal energy delivered.[14]

Clinical scenarios are always different from experimental set ups and irrespective of acceptable efficacies of any techniques previously described, there is always a risk of enamel damage, thermal injury to pulp and inhalation of ceramic debris by patients.

Larmour et al.[15] investigated the effects of certain essential oils (EOs) and phenolic agents on the debonding behavior of ceramic brackets. Peppermint oil was used as a debonding agent and it proved helpful in removal of residual resin from the enamel surface by a significant softening of resin.[16] Apart from peppermint oil the effect of ethanol, eucalyptus oil, and hot water have been studied. Among these, immersion of brackets for 10 minutes in eucalyptus oil significantly reduced the bond strength compared with control groups.[15-17] The effect of EOs like lemon oil and glutathione on the debonding behavior of ceramic brackets is yet to be researched and this study was an attempt to explore this possibility. The present study evaluated and compared the debonding force, adhesive remnant index (ARI) and damage to tooth structure following debonding ceramic brackets after being immersed in 3 different chemical reagents (eucalyptus EO, glutathione oil and lemon EO) and (distilled water) for ten minutes. The null hypothesis was “there was no difference in the debonding force, the adhesive remnant score and damage to enamel between groups bonded with ceramic brackets immersed in distilled water, eucalyptus oil, glutathione and lemon EO.”

METHODS

Sample size was calculated using G*Power (ver 3.1.9.2) with data taken from a previous study.[15] A sample size of 92 was estimated with an effect size of 0.272, alpha error of 0.20 and 80% power of the study. However, sample size was increased to 100 anticipating tooth fracture or other eventualities, which would result in exclusion of the samples.

This study involved four groups (three experimental groups and one control group); with 25 samples in each group.

- Group I: Control group/Distilled water
- Group II: Eucalyptus oil
- Group III: Glutathione oil
- Group IV: Lemon EO

Premolar teeth were extracted, and teeth with sound enamel were selected for this study. Teeth with caries, hypoplastic enamel, or restoration on the buccal surface and teeth with enamel cracks were excluded. Samples were cleaned to remove debris and calculus by scaling and polishing, then stored in distilled water at room temperature for a period of one week. The teeth were then mounted in resin blocks along the long axis. The teeth with blocks were cleaned using pumice slurry, rinsed with water and dried with compressed air. Orientation marks on vertical and horizontal axes were marked on the buccal enamel surface to guide in bonding the brackets. All bonding procedures were performed by the same operator according to the manufacturer’s instructions. The buccal enamel surfaces were etched with 37% phosphoric acid gel for 20 seconds, rinsed for 60 seconds, and dried with compressed air, bonding agent was applied using an applicator tip and cured, followed by the placement of ceramic bracket 3M Clarity, (3M, Monrovia, Calif, USA) using a bracket positioner on to the tooth and excess flash was removed. A positioning gauge was used to orient the ceramic bracket according to the marks placed on the buccal tooth surface and light cured. The samples were then placed in distilled water for 1 week to allow complete polymerization of the resin.[15]

EOs are usually used in 0.5%-5% concentration. However, 2% concentration is most commonly used as a safe dose to prevent any unwanted irritation of the oral mucosa. The concentration of the reagents used for this experiment was that of a mouth rinse since the purpose of the reagent is external application and not to be used systemically. A good rule of thumb when seeking to make 2% dilution is to add 10-12 drops of EO to each fl. ounce (30 mL) of carrier (water).[18] Teeth samples with bonded ceramic brackets were immersed for 10 min in their respective chemical reagents. Following the immersion, they were subjected to debonding.

A material testing machine was used to measure and record the force required during debonding procedure in this study. Each tooth was placed in a fixture provided in the Universal Testing Machine (Instron 5566, Norwood, Mass, USA) to simulate the firm grip of the tooth inside the bone socket in the oral cavity. This procedure was done to avoid experimental errors due to specimen movement which may be caused by the force exerted by the material testing machine. The brackets were removed by applying shear load through cross head blades of testing machine as recommended previously.[19] The debonding force was displayed as a digital readout (in Newtons) in the universal testing machine, operating with a cross-head speed of 1 mm per minute. The magnitude of the debonding force which was recorded in newtons (N) was further converted to mega pascal (MPa) by dividing the newton value with the surface area of the bracket base (9.61 mm^2) as per manufacturer instructions.

The ARI scores were used to examine the site of bond failure and classify the distribution patterns of residual adhesive.[20] This index consists of the following scoring:

- Score 0= No adhesive left on the tooth surface
- Score 1= Less than half of the adhesive left on the tooth surface
- Score 2= More than half of the adhesive left on the tooth surface
- Score 3= All adhesive left on the tooth surface

Four specimens, randomly selected from every group, were examined with a scanning electron microscope (SEM) to obtain a micrograph of the surface enamel after debonding. The samples were sectioned using a rotary handpiece into small sections for ease of evaluation. Sectioning was performed distal to the buccal cusp of the premolar in the occluso- cervical direction in a smooth motion to maintain the integrity of the hard tissue. All samples were then conventionally metallized (Gold sputtering JEOL JFC 1100E) and observed under a SEM.

Statistical Analysis

The data were analysed using SPSS software (IBM SPSS software for windows, version 23.0, Armonk, NY) for normality using Shapiro-Wilk test, since the data was not normally distributed, Welch's one-way ANOVA was performed to compare debonding force between the groups. Multiple comparisons between the groups were carried out by Games-Howell post-hoc test.

The frequency distribution was used to present the categorical data representing the ARI scores. The mean rank is the average of the ranks for all observations with each group of the study, which implies that the group with the lowest mean rank has the least ARI scores. As the distribution was not normal, ARI scores were analysed using Kruskal-Wallis test followed by the Dunn test for pairwise comparisons between groups.

RESULTS

The mean debonding force of the groups are given in descending order- control was 121.44 Newton (N) followed by 68.44 N in the lemon EO group, 56.46 N in the eucalyptus oil group and the least was exhibited by specimens immersed in glutathione (50.56N). There was a statistically significant difference in the mean scores of the debonding force between the groups (p=0.001) (Table 1).

Table 2 indicates that there was a significant difference of debonding forces between glutathione and eucalyptus oil with other two groups. Thus, debonding force drastically reduced when the samples were immersed in glutathione and eucalyptus oil.

For ease of comparison and comprehension, debonding force values were converted into megapascals to arrive at shear

Table 1. Comparison of debonding force between different groups

	N	Mean (Newtons)	Mean (MPa)	SD	Std. error	F	Sig.
Control	25	121.44	11.56	28.781	5.756		
Eucalyptus	25	56.48	5.37	15.785	3.157	77.361	p=0.001*
Glutathione	25	50.56	4.81	10.775	2.155		
Lemon oil	25	68.44	6.51	12.583	2.517		

Level of significance at p<0.05
SD, Standard deviation; N, Number of specimens
*Statistically significant at p<0.01 using Welch's One-Way ANOVA (unequal variances)

Table 2. Results of Games-Howell post-hoc test

(I) Groups	(J) Groups	MD (I-J)	Sig.
Control	Eucalyptus	64.96	0.001*
	Glutathione	70.88	0.001*
	Lemon oil	53	0.001*
Eucalyptus	Glutathione	5.92	0.42
	Lemon oil	-11.96	0.024**
Glutathione	Lemon oil	-17.88	0.005*

Level of significance at p<0.05; MD, Mean difference
Statistically significant at p<0.05**and p<0.01 *using Games-Howell post-hoc test for unequal variance

bond strength during debonding (Table 1). It was found that specimens immersed in glutathione exhibited the least shear bond strength (4.81MPa) followed by specimens immersed in eucalyptus oil (5.37MPa), lemon EO (6.51MPa) and highest in control (11.56MPa).

Teeth immersed in glutathione had the highest proportion (76%) of specimens without any adhesive remnants (score 0), followed by specimens in eucalyptus oil (64%). About 12% of samples immersed in lemon oil had a score 3 that indicated half of the composite was on the enamel surface and rest half on the bracket base, 4% of specimens immersed in eucalyptus oil had a score 2. None of the specimens immersed in glutathione had either score 2 or 3. Control group had the highest percentage of specimens (20%) with score 3 suggesting that the entire composite was left on the enamel surface (Table 3).

There was a statistically significant difference in adhesive remnant scores between different groups, (p=0.001) with mean rank scores of 68.4 for group I, 42.16 for eucalyptus oil group, 36.20 for glutathione group and 55.24 for lemon EO group, respectively. The mean rank was lowest in the glutathione group, indicating poor ARI scores, implying that no adhesive was left behind after debonding, when specimens were immersed in glutathione (Table 4). There was a statistically significant difference between the mean ranks of the control and eucalyptus oil groups (p=0.003) and between the control and glutathione groups (p=0.000). However, there was no difference between the other groups (p>0.05) (Table 5).

When specimens immersed in distilled water were observed under 200X magnification, presence of enamel cracks were revealed (Figure 1). Thus, teeth immersed in distilled water

Table 3. Frequency and percentage of adhesive remnant index scores in different groups

		Adhesive remnant index scores				
		0	**1**	**2**	**3**	**Total**
Control	N	6	9	5	5	25
	%	24.00%	36.00%	20.00%	20.00%	100.00%
Eucalyptus	N	16	8	1	0	25
	%	64.00%	32.00%	4.00%	0.00%	100.00%
Glutathione	N	19	6	0	0	25
	%	76.00%	24.00%	0.00%	0.00%	100.00%
Lemon oil	N	10	11	3	1	25
	%	40.00%	44.00%	12.00%	4.00%	100.00%

N, Number of specimens; %, Percentage

Table 4. Mean rank of adhesive remnant index scores

Groups	N	Mean Rank	χ^2 value	Sig.
Control	25	68.40	22.153	p=0.001*
Eucalyptus	25	42.16		
Glutathione	25	36.20		
Lemon oil	25	55.24		
Total	100			

Level of significance at p<0.05 N, Number of specimens *Statistically significant at p<0.05 using Kruskal-Wallis test

Table 5. Pairwise comparison using Dunn test

Pairwise Comparisons of Groups					
Sample 1-Sample 2	**Test statistic**	**Std. error**	**Std. test statistic**	**Sig.**	**Adj. Sig.[a]**
Glutathione- Eucalyptus	5.960	7.463	0.799	0.425	1.000
Glutathione- Lemon oil	-19.040	7.463	-2.551	0.011	0.064
Glutathione- Control	32.200	7.463	4.315	0.000	0.000
Eucalyptus-Lemon oil	-13.080	7.463	-1.753	0.080	0.478
Eucalyptus- Control	26.240	7.463	3.516	0.000	0.003
Lemon oil- Control	13.160	7.463	1.763	0.078	0.467

Each row tests the null hypothesis that the sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.
[a]: Significance values have been adjusted by the Bonferroni correction for multiple tests

clearly exhibited the presence of enamel damage caused due to the higher debonding force. Teeth immersed in eucalyptus oil showed a clear enamel surface in the debonded site under 20X magnification. Under 200X magnification, teeth immersed in eucalyptus oil showed no signs of enamel damage, but the roughened enamel surface could be appreciated which suggested the presence of remnant resin at the microscopic level (Figure 2). Glutathione showed the cleanest enamel surface post debonding, magnification under 200X showed no sign of damage to the enamel surface (Figure 3). Specimens of the lemon essential oil group under 20X magnification showed a mesh pattern of the resin left on the tooth surface (ARI score of 3) which was further appreciated under 200X magnification. Though there was lot of resin on enamel surface, there was no sign of enamel damage (Figure 4).

DISCUSSION

Ceramic brackets are made of aluminum oxide and two types, mono- and polycrystalline, that vary in strength, translucency and fracture toughness.[21] Due to their natural brittleness, debonding of ceramic brackets is challenging because of fractured brackets and enamel damage.[21-23] The study was conceived with the aim of testing a new reagent that can reduce the debonding force of ceramic brackets so that enamel damage is prevented and patient discomfort during debonding is alleviated.

EOs are natural, volatile complex compounds that possess anti-oxidant and antimicrobial properties, are derived from aromatic plants, soluble in organic solvents but exhibit hydrophobic nature with density lower than water.[24-27] There has been no published research on the effect of glutathione on the bond strength of ceramic brackets. This study was conducted to evaluate the debonding force, Remnant Adhesive Index and damage to tooth structure as assessed by SEM, immersed in three different chemical reagents.

In this study, it was observed that teeth immersed in distilled water (control) had the highest debonding force, followed by teeth immersed in lemon EO, eucalyptus oil and the least force was required to debond brackets immersed in glutathione (Table 1). Though the force registered was similar for eucalyptus

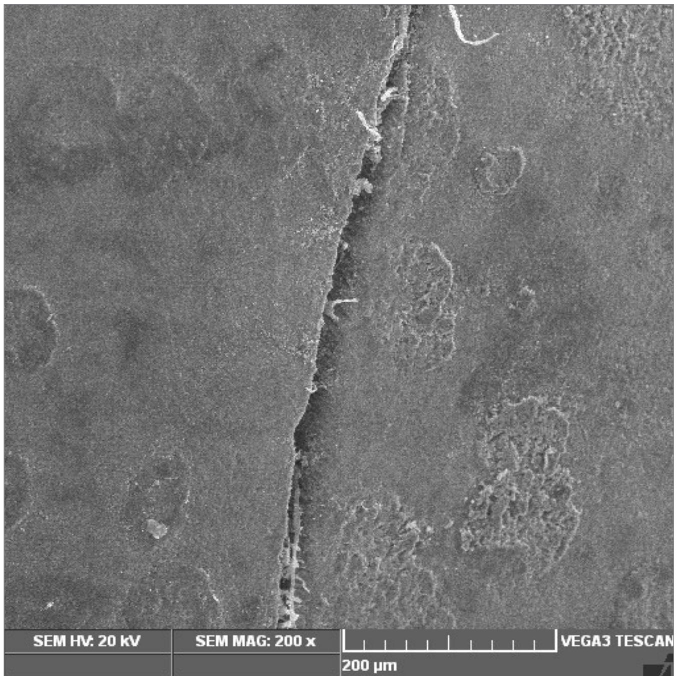

Figure 1. 200X magnification of control group showing crack propagation under SEM

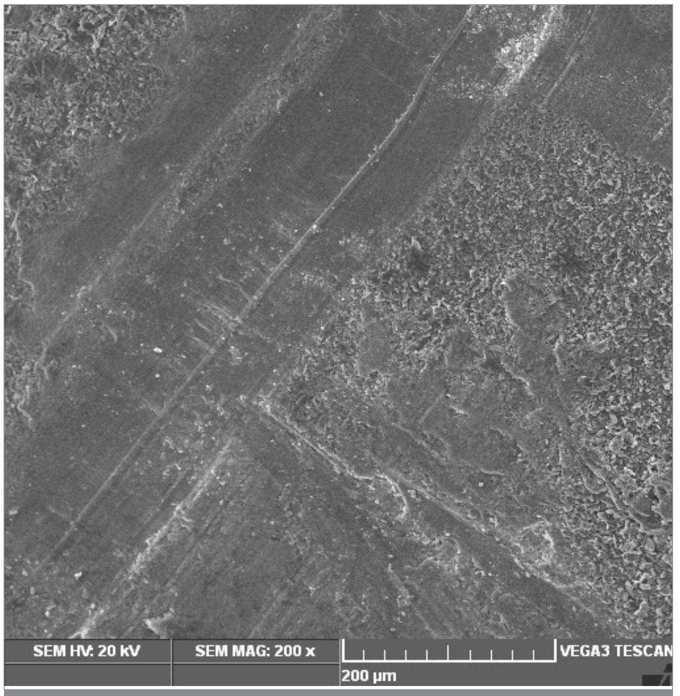

Figure 2. 200X magnification of eucalyptus oil group showing no cracks on enamel surface under SEM

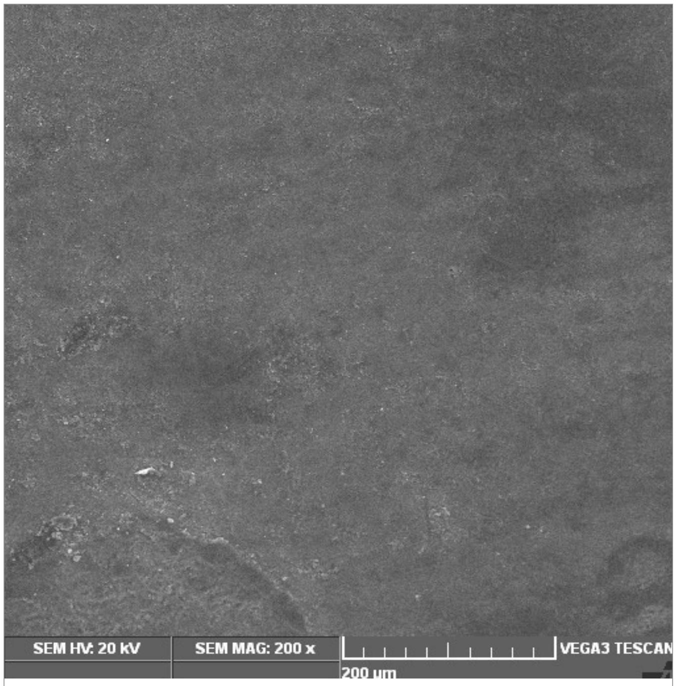

Figure 3. 200X magnification of glutathione group showing no damage to enamel structure under SEM

oil and glutathione group, there was a statistically significant reduction in the debonding force of brackets immersed in glutathione. Glutathione is a low molecular weight thiol and is one of the best antioxidants. It is probable that it enhanced marginal leakage between the tooth and cement interphase and thereby facilitated debonding of ceramic brackets.[18]

The specimen treated with eucalyptus oil had a mean debonding force of 56.48 N. Yu et al.[17] investigated the effect of eucalyptol on the debonding of metal and ceramic brackets and concluded that specimens immersed in eucalyptol gel for 10-15 in exhibited most reduction in shear bond strength. Larmour et al.[15] reported an immersion time of one hour in peppermint oil, whereas in this study, immersion time was reduced to a clinically acceptable level of ten minutes.[16]

A thorough analysis of various chemical compounds used in the formulation of EOs indicated a higher concentration of an organic compound 1-8 Cineole.[28] This may be responsible for lowering the shear bond strength of the composite resin by softening it. It can be the key ingredient in facilitating debonding of ceramic brackets, but this question requires extensive research. The mean debonding force of teeth immersed in lemon EO was 68.44 N, this value was the highest among the experimental groups. The effectiveness of lemon EO in debonding orthodontic ceramic brackets has not been previously studied; therefore, further research is necessary before a meaningful conclusion can be derived.

It was observed that 76% of specimens immersed in glutathione and 64% of specimens in eucalyptus oil had scores 0 in ARI, they did not have any remnant adhesive on enamel (Table 3). This result is more promising than the study by Devi Kanth et al.[29], where score 0 was observed for 60% of specimens that were treated with EO (peppermint oil) for 5 min before debonding. Lemon EO group had about 44% of the specimens with 50% of the adhesive still on the enamel surface. There was a statistically significant difference in the mean ranks of all groups (Table 4). Pairwise comparisons revealed no statistically significant difference between group II (eucalyptus oil) and group III (glutathione) (Table 5). Similarly, intergroup comparison of debonding force (Table 2) also did not reveal statistical differences between eucalyptus oil and glutathione, but ceramic brackets in the glutathione group exhibited peel-off effect, composite resin peeled off totally from the enamel surface (Figure 5). This observation was not evident in any other group. The ARI scores were lower in the experimental groups than in the control group, thus reflecting a reduction in resin retained on the enamel surface. The reason for the reduction in ARI scores can be an infiltration of EOs in enamel-adhesive interface, thus facilitating crack propagation, resulting in easy debonding of ceramic brackets.

Uysal et al.[30] evaluated the shear bond strength of ceramic and metal brackets and found that ceramic brackets bonded with the normal acid etch technique had the highest levels of shear bond strength (36.7MPa) among the groups investigated. Similar results were obtained in the research by Odegaard and Segner.[23] The mean values of shear bond strength obtained in this study were 11.56MPa in the control group and 5.37MPa, 4.81MPa and 6.51MPa in specimens immersed in eucalyptus oil, glutathione and lemon EO, respectively (Table 1). It was evident that, immersing the teeth bonded with ceramic brackets in EOs used in this study reduced the shear bond strength to a considerable extent. Thus, the null hypothesis was rejected. This finding was further reinforced by the ARI scores. In SEM images, the control group had a noticeable crack formation on enamel. Among the experimental groups, specimens immersed in eucalptus oil did not show any enamel damage but displayed minor surface irregularity, specimen in lemon EO group showed residual adhesive and the sample immersed in glutathione exhibited a smooth surface. There was no enamel pitting in the specimens in contrast to the results of study by El-Shourbagy and Ghobashy.[16]

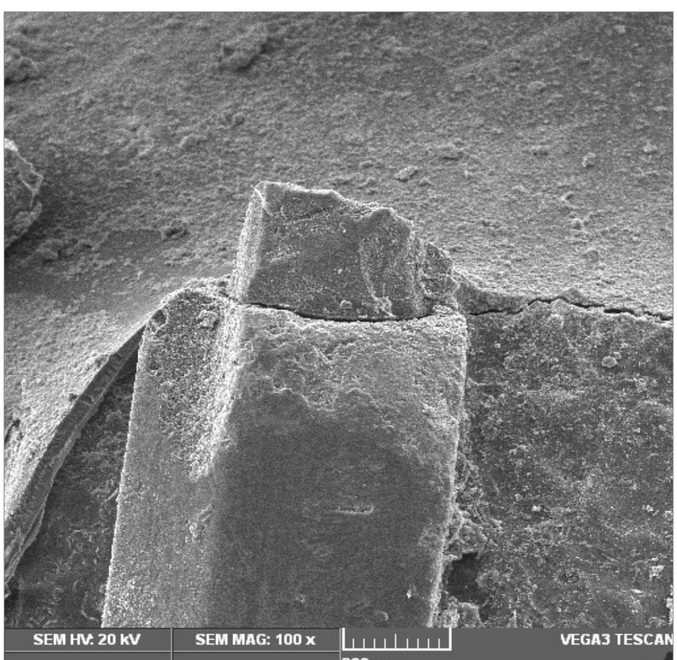

Figure 4. 100X magnification showing adhesive left behind on tooth surface after the use of lemon essential oil under SEM

Figure 5. Peel off effect: entire composite is on the bracket surface after debonding of specimens immersed in glutathione (group III)

The findings indicated a definitive effect of softening resin when teeth bonded with ceramic brackets were immersed in chemical reagents. The antioxidant properties of glutathione might be the key reason for the excellent peel-off effect of the composite from the enamel surface, which can be considered beneficial as it would save clinical chair side time as well as eliminate the need to use rotary instruments to remove composite remnants. Glutathione holds promise as a better reagent compared with others, when the results of the three parameters tested are correlated.

Though this study was performed *in vitro*, further research with glutathione will improve the scope of using the same in day-to-day practice so that ceramic brackets can be debonded with ease, reducing chair side time, eliminating patient discomfort and obviating the chances of damage to surface enamel.

CONCLUSION

Immersion of teeth bonded with ceramic brackets in chemical reagents for a duration of 10 min reduced the debonding force, adhesive remnant on the enamel surface as well as prevented damage to the enamel structure compared to the control.

Of the three reagents used, specimens immersed in glutathione showed the highest reduction in debonding force that enabled easier debonding of ceramic brackets with peel-off effect. Thus, it can be concluded that immersion in glutathione for a duration of 10 min for debonding of ceramic brackets is a promising method to reduce debonding force, ARI scores and preventing damage to enamel surface.

Ethics

Ethics Committee Approval: This study was approved by the Scientific Review Board of SRM Dental College, Ramapuram, Chennai-89 (SRMDC/IRB/MDS/2018/No.108).

Informed Consent: Informed consent was obtained from patients before extraction of premolar teeth.

Peer-review: Internally peer-reviewed.

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Declaration of Interests: The authors have no conflicts of interest to declare.

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Original Article

In Vitro Evaluation of the Effects of Different Chemical Solvent Agents on Shear Bond Strength of Ceramic Orthodontic Brackets

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Main Points

- Ceramic bracket pieces remained on the tooth surface and enamel cracks occured during debonding process.
- The ethanol 5 min and 15 min groups had the highest SBS values and most damaged SEM images of the enamel.
- The lowest SBS values were observed in the acetone 5 min and 15 min groups.
- The acetone application can be considered an effective clinical method for the future.

ABSTRACT

Objective: In this study, the effects of different chemical solvents such as acetone, ethanol, dimethyl sulfoxide (DMSO), peppermint oil, and hot water on the shear bond strength (SBS) of mechanically and chemically bonded ceramic brackets were examined. Their use for facilitation of the debonding process in practice was evaluated regarding the purposes of this study.

Methods: One hundred and thirty-two human premolar teeth extracted for orthodontic purposes were randomly divided into 11 groups. SBS were applied using a universal test machine. The amount of residual adhesives was determined through adhesive remnant index scoring. Scanning electron microscopy (SEM) images were examined to determine the effects of solvents on the enamel surface.

Results: In all test groups, the highest SBS values were found in the ethanol 5- and 15-minutes groups. SEM examination showed micro-cracks in all groups. Increased SBS values were also found in 5- and 15-minutes groups of hot water and DMSO, while both peppermint oil groups had similar SBS values as the control group. SBS values of both acetone 5- and 15-minutes groups were found to be lower than the control and other groups.

Conclusion: Acetone application for 5 or 15 minutes before debonding of ceramic brackets could be an alternative clinical approach to prevent enamel damage and facilitate debonding.

Keywords: Acetone, ceramic bracket, ethanol, organic chemical solvent, shear bond strength

INTRODUCTION

During the entire treatment period, orthodontic brackets must resist mechanical and masticatory forces and have a bond strength of at least 6-8 megapascal (MPa).[1] However, this desired bond strength should not exceed approximately 13.75 MPa, which is the cohesive internal strength of the enamel, in order not to damage the tooth enamel during the debonding of the brackets.[2] However, since ceramic brackets do not have the flexibility to stretch as much as stainless steel brackets, they cannot be removed by deforming at the end of orthodontic treatment.[3,4] According to *in vitro* bond strength tests performed with ceramic brackets, it was observed that the fracture occurred frequently at the enamel-adhesive interface, and it was found that these forces could reach up to 28.3 MPa.[5] Depending on this situation, the integrity of the tooth enamel may be disrupted during the debonding process of the ceramic brackets, ceramic bracket pieces may remain on the tooth surface, and

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sometimes permanent damages such as enamel cracks and failures may occur as malpractice.[6-9] Residual composites and bracket remnants may cause rough surfaces and be a risk factor for maintaining oral hygiene after the debonding process so the ceramic brackets are often not indicated in children because of the less treatment compliance and the poor oral hygiene of these patients.[10-12] In addition, the use of ceramic brackets is contraindicated in syndromic patients with hypoplastic and hypocalcific enamel such as oral-facial-digital syndrome.[13,14] Also the risk of enamel fracture during debonding is high in teeth with endodontic treatment and large restorations.[15] Enamel tissue loss occurs at a depth of 5-50 µm due to the roughening of the tooth surface with acid during the bonding of the brackets, and irreversible hard tissue losses of around 100-150 µm occur with the effect of composite remnant removal procedures.[3,4] Different techniques such as electrothermal, laser and ultrasonic debonding have been tried supporting the mechanical removal of the brackets to prevent such problems during the removal of ceramic brackets.[2,16] Due to the irreversible pulp damage and the gingival irritation risks that can be caused by these techniques, it has become necessary to try alternative methods for the debonding of ceramic brackets.

In our study, it was aimed to reduce the debonding force required during the debonding process of ceramic brackets and to reach the range of 12.75-13.75 MPa, which is considered the safe limit for the integrity of the tooth enamel as stated in the literature.[2] The purpose of this study was to evaluate the effects of different chemical agents that were predicted to dissolve the organic matrix of orthodontic adhesive. Under in vitro conditions, different chemical solvents were applied to the enamel-adhesive and adhesive-bracket interfaces to develop a new technique that can be used in orthodontic clinics to protect the enamel.

METHODS

This research was conducted in compliance with the Helsinki Declaration, and the protocol was authorized by the University of Istanbul Ethics Committee in Istanbul, Turkey (Protocol number: 2019/11).

An initial statistical evaluation for sample size calculation was performed considering a power of 90% (α=0.05, 1- β=90%). This analysis suggested a minimum sample size of 12 teeth.

In our study, there are 11 groups, each consisting of 12 teeth, and 132 mandibular and maxillary human premolar teeth extracted for orthodontic purposes. The teeth that were found to have cavity, crack, filling, or dental extracting forceps damage because of the examination under light were excluded from the study. It was prioritized that the tooth surfaces had not been treated with any chemical agent before and that the buccal surfaces were smooth.

After the periodontal ligament remnants on the root surfaces of the extracted teeth were debrided with a periodontal curette, the extracted teeth were kept in distilled water renewed twice a week at room temperature until the experiments were started. The enamel surfaces of all teeth were cleaned with a fluoride free paste and polishing brush using a low-speed air-cooled micromotor and contra-angle handpiece without using any abrasive agents, then washed with air-water spray and dried.

Ceramic 0.018"x0.022" slot orthodontic brackets (Ortho Technology, PURE Sapphire Bracket System, Opal Orthodontics, South Jordan, UT, USA) were bonded to the tooth surface using 37% orthophosphoric acid, primer (Transbond XT, 3M Unitek, Monrovia, CA, USA) and adhesive (Transbond XT, 3M Unitek, Monrovia, CA, USA). Guide labels were used to ensure that the brackets were in the middle 1/3 area in the mesiodistal and occlusogingival directions and parallel to the long axis of the tooth. To standardize the applied force, heavy elastic of 6 1⁄2 ounce, 1/8 size was placed on the tooth in such a way that it would surround the equatorial line of the tooth and include the bracket. A new elastic was used for each sample and to prevent different forces that may occur due to the dimensional differences among the premolar teeth, 200 g force was measured each time with a dynamometer and the resin remnants around the bracket were cleaned with the help of a probe. Afterwards, the adhesive was polymerized with an LED light device (3M Elipar-S10, 3M ESPE, St. Paul, MN, USA) emitting light at a wavelength of 430-480 nanometer for 20 seconds.

The prepared samples were immersed in water baths at 5 °C and 55 °C, respectively, 1000 times each, resulting in thermal stress. The waiting time for each bath was set to be 20 seconds and the transfer time between the baths to be 10 seconds. The sample teeth were placed vertically on the acrylic blocks with the help of a reference wire, with all of their crowns exposed and their roots in the acrylic.

In our study, there are 11 groups, each consisting of 12 teeth, formed by applying 5 different organic chemical solvents [acetone, ethanol, dimethyl sulfoxide (DMSO), peppermint oil, hot water] to the teeth before debonding for two different durations (5 min and 15 min), with the control group. 99.8% acetone, 99.5% ethanol, 99.9% DMSO, 100% pure peppermint oil and 60 °C hot water were used in this regard.

The solutions poured into a 250 milliliter beaker were divided into 12 glass beakers with a depth of 40 millimeter (mm) and an inner diameter of 15 mm, separate one for each sample, using a pasteur pipette. The samples were placed in glass beakers so that the tooth surface with the brackets remained in the solution, and they were kept waiting until the time elapsed using a chronometer. Since the samples prepared in steel molds with an inner diameter of 18 mm were placed in glass test beakers with an inner diameter of 15 mm, only the tooth crowns were kept in solution, and by preventing the contact of acrylic with the solution, the release of chemicals from the acrylic to the solution was prevented (Figure 1a).

Debonding test was applied to each sample, which was kept in chemical solutions, immediately after 5-minute and 15-minute durations, and the samples were kept in the biopsy container with the stripped bracket to measure the failure force and measure adhesive remnant index (ARI) scoring. For the control group, after the brackets adhered to the tooth surface, the teeth were embedded in the acrylic base following the thermal cycle process and the failure forces were measured with a (Buehler Instron, Buehler United Kingdom Warwick Manufacturing Group, Coventry, United Kingdom) without being kept in any solution (Figure 1b). The speed of the movable top plate of the test machine was set to 1 mm/minute, the maximum force to be applied by the machine was set to 500 N, and the measurements were performed with an accuracy of 0.2 N. The measured forces (Newton) were divided by the base surface areas of the brackets, and the amount of force per unit area was converted into MPa (MPa=N/mm^2). The base surface area of the bracket used was determined by contacting the manufacturer and was taken as 13.12 mm^2.

After the debonding tests, the tooth surfaces were examined under x15 zoom and bracket bases x25 zoom with a double-ocular stereomicroscope device (Nikon SMZ 1000) and the images were recorded one by one with the "Camera" computer program.

Since we used ceramic brackets in our study, the amount of residual adhesive on the tooth surface was determined by the modified version by Bishara and Trulove[7,8] in 1990 of the ARI defined by Artun and Bergland.

To evaluate the effects of the applied solutions on both enamel and adhesive, samples with an ARI score of 2 or 3 were selected and images at ×40, ×100, ×500 and ×1000 zoom were photographed with the scanning electron microscopy (SEM) device (JEOL JSM 6510-LV). The images of the enamel surfaces were evaluated according to the ARI system.

Statistical Analysis

SPSS (version 22.0;SPSS,Chicago,Il, USA), was used for statistical analysis. The ANOVA test was used to compare more than two independent groups and the homogeneity of variances assumption is provided in the comparison of the variables, and the double-sided Dunnett t-test was used as the post-hoc test for the comparison of the variables that were found to be statistically significant with the control group. Welch ANOVA test was used to compare the variables with normal distribution but not with the homogeneity of variances assumption, and Dunnett t3 test was used for pairwise comparison of statistically significant results between groups. The p value of .05 was considered as the level of significance. The ARI score values of the samples were determined as percentage distributions according to the groups.

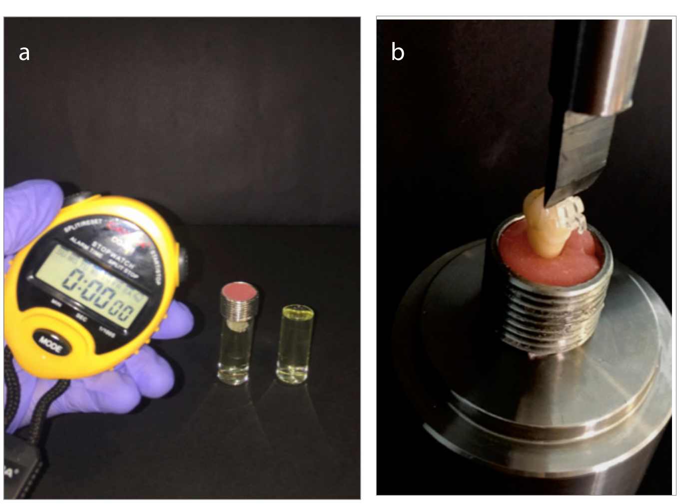

Figure 1. (a) Application of the solvents, (b) Shear force applied with the Universal Test Machine.

RESULTS

Comparison of the control group with all of the other groups is listed in Table 1. Pairwise comparison of the control group with the other groups is described in Table 2. Comparison of the SBS values of the 5 min groups within themselves is shown in Table 3, whereas comparison of the SBS values of the 15 min groups within themselves is shown in Table 4. Table 5 compares the SBS values of samples kept in the same solution for short (5 min) and long (15 min) durations. The ARI score distributions of the samples are shown in Table 6.

It was observed that hot water and DMSO did not soften the composite; in contrast, they increased the shear bond strength value by hardening, while peppermint oil did not have any effect on softening or hardening of the composite (Table 1).

Table 1. Comparison of SBS values between groups

	N	SBS value Mean ± SD		p value
Control group	12	18.86	3.99	
Acetone 5 min	12	13.99	1.41	
Acetone 15 min	12	11.66	1.20	
Ethanol 5 min	12	32.53	7.31	
Ethanol 15 min	12	30.83	6.84	
DMSO 5 min	12	24.83	4.19	0.000*
DMSO 15 min	12	22.88	3.05	
Peppermint oil 5 min	12	19.25	3.79	
Peppermint oil 15 min	12	17.18	3.67	
Hot water 5 min	12	24.93	4.86	
Hot water 15 min	12	25.17	5.76	

ANOVA test; *p<0.05; SBS, shear bond strength; SD, standard deviation

The shear bond strength value of the acetone 5-minute and acetone 15-minute groups was found to be significantly lower than that of the control group and the other chemical solutions with the same duration (Table 2, Table 3 and Table 4).

The mean of the SBS values for the acetone 15 min group is statistically significantly lower than that of the acetone 5 min group (Table 5).

Considering the ARI scores, adhesive fracture (at the enamel-adhesive interface) was observed for a large percentage of samples. Enamel fractures (ARI score 4) (Figure 2a) and bracket fractures (ARI score 5) (Figure 2b) were observed as well (Table 6).

A rougher surface was observed for the acetone, peppermint oil, and hot water groups compared to the control group when SEM images were examined. Among all these groups, the enamel surface exhibited a more irregular structure for the DMSO-applied groups (Figure 3), and it was observed that ethanol was the most damaging solution to the enamel surface.

Table 2. Pairwise comparison of the SBS values between control group and other groups

Group (I)	Group (J)	Mean difference (I-J)	SE	p value
Acetone 5 min	Control	- 4.88	1.87	0.003*
Acetone 15 min	Control	-7.20	1.87	0.002*
Ethanol 5 min	Control	13.67	1.87	0.001*
Ethanol 15 min	Control	11.97	1.87	0.001*
DMSO 5 min	Control	5.96	1.87	0.06
DMSO 15 min	Control	4.01	1.87	0.207
Peppermint oil 5 min	Control	0.39	1.87	1.000
Peppermint oil 15 min	Control	-1.69	1.87	0.958
Hot water 5 min	Control	6.07	1.87	0.013*
Hot water 15 min	Control	6.30	1.87	0.009*

Dunnett t-test (double-sided); *p<0.05; SE, standard error

Table 3. Comparison of SBS values of 5 min groups within themselves

5 min group (I)	5 min groups (J)	Mean difference (I-J)	SE	p value
Acetone	Ethanol	-18.55	2.15	0.000*
	DMSO	-10.84	1.28	0.000*
	Peppermint oil	-5.26	1.17	0.005*
	Hot water	-10.94	1.46	0.000*
Ethanol	DMSO	7.70	2.43	0.049*
	Peppermint oil	13.28	2.37	0.000*
	Hot water	7.60	2.53	0.066
DMSO	Peppermint oil	5.58	1.63	0.023*
	Hot water	-0.10	1.85	1.000
Peppermint oil	Hot water	-5.68	1.78	0.041*

Dunnett t3-test; *p<0.05; SE, standard error

DISCUSSION

In our study, to prevent the side effects that may occur during the removal of ceramic brackets with different techniques such as

Table 4. Comparison SBS values of the 15 min groups within themselves

15 min group (I)	15 min groups (J)	Mean difference (I-J)	SE	p value
Acetone	Ethanol	-19.16	2.01	0.000*
	DMSO	-11.21	0.95	0.000*
	Peppermint oil	-5.52	1.12	0.002*
	Hot water	-13.51	1.70	0.000*
Ethanol	DMSO	7.96	2.16	0.020*
	Peppermint oil	13.65	2.24	0.000*
	Hot water	5.67	2.58	0.302
DMSO	Peppermint oil	5.70	1.38	0.004*
	Hot water	-2.29	1.88	0.903
Peppermint oil	Hot water	-7.99	1.97	0.007*

Dunnett t3-test; *p<0.05; SE, standard error

Table 5. Comparison of groups in the same chemical solution at different durations

	N	SBS value (Mean ± SD)	SE	p value
Acetone 5 min	12	13.98 ± 1.41	0.41	0.001*
Acetone 15 min	12	11.66 ± 1.20	0.35	
Ethanol 5 min	12	32.53 ± 7.31	2.11	0.563
Ethanol 15 min	12	30.83 ± 6.84	1.98	
DMSO 5 min	12	24.83 ± 4.19	1.21	0.206
DMSO 15 min	12	22.88 ± 3.05	0.88	
Peppermint oil 5 min	12	19.25 ± 3.79	1.09	0.187
Peppermint oil 15 min	12	17.18 ± 3.67	1.06	
Hot water 5 min	12	24.93 ± 4.86	1.40	0.914
Hot water 15 min	12	25.17 ± 5.76	1.66	

ANOVA test; *p<0.05; SBS, shear bond strength; SD, standard deviation; SE, standard error electrothermal, laser and ultrasonic debonding; organic chemical solvent agents such as acetone, ethanol, DMSO, peppermint oil and hot water were considered to be applied as an alternative to these techniques during the debonding stage.[2,16] It was hypothesized that the application of these chemical dissolving agents to the tooth surface before debonding could achieve failure with the least damage and with the lowest forces, and the highest concentrations of these chemical dissolving agents were used to see the maximum effect. DMSO was preferred in our study considering its ability to dissolve many substances better than water and its antimicrobial, anti-inflammatory and analgesic effects. In the literature, studies have supported that peppermint oil softens the adhesive and reduces the shear bond strength (SBS) of the ceramic brackets, but there are also studies stating that this agent is effective only when applied for a long duration.[17-19] In our study, the effect of ceramic brackets on the debonding test was evaluated comparatively by applying the same agent for both short and long durations. In the orthodontic literature, there is only one study sharing clinical experience on the effect of hot water on the removal of ceramic brackets.[20] Regarding the determination of the temperature of hot water included in our study, hot water was applied by determining a safe temperature (60 °C) level that would not damage the oral tissues and pulp but would soften the composite "if it had any effect".

Although all teeth can be used in the *in vitro* studies[21], generally, premolar teeth extracted for orthodontic purposes are used for shear or tensile tests.[6,22,23] The lower and upper human premolar teeth with complete root development and extracted for orthodontic treatment from individuals aged 12-17 years were used in our study. The use of premolar teeth of individuals in the

a

b

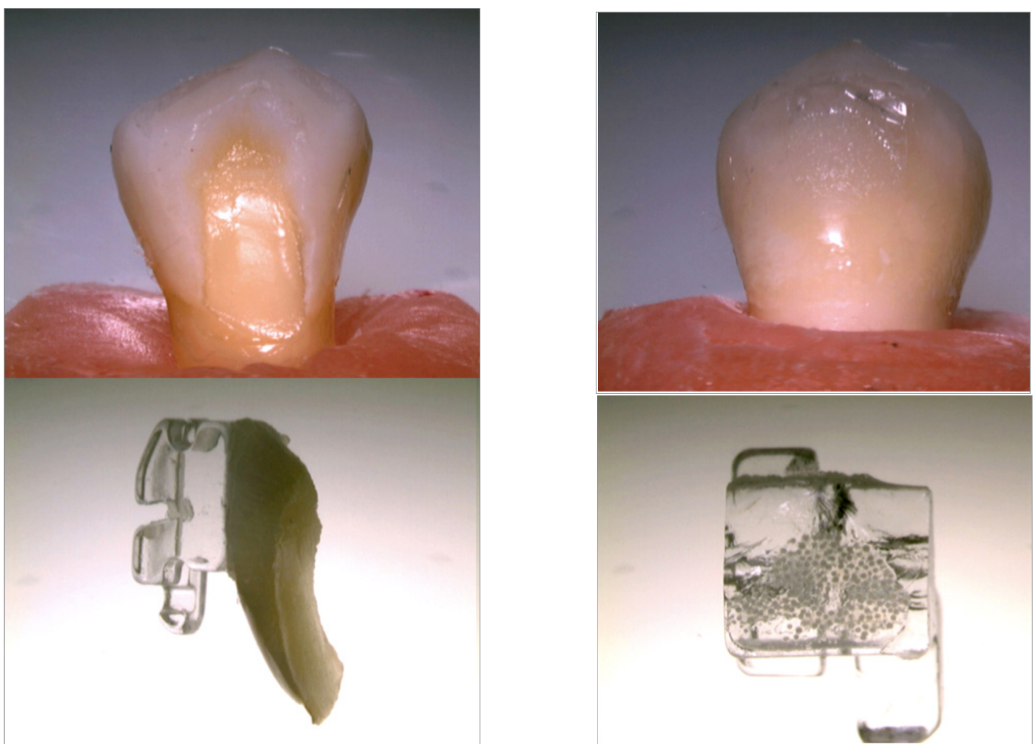

Figure 2. (a) Enamel fracture (ARI score 4), (b) Bracket fracture (ARI score 5)
ARI, adhesive remnant index

Table 6. Distribution of the samples according to ARI score

	Control group	Acetone 5 min	Acetone 15 min	Ethanol 5 min	Ethanol 15 min	DMSO 5 min	DMSO 15 min	Peppermint oil 5 min	Peppermint oil 15 min	Hot water 5 min	Hot water 15 min	N (%)
ARI 0	1	5	5	5	2	6	7	2	7	10	8	58 (44%)
ARI 1	6	2	3	3	5	5	1	2	4	1	2	34 (25.8%)
ARI 2	2	0	2	1	1	0	0	3	0	0	1	10 (7.6%)
ARI 3	0	1	0	0	2	1	1	3	1	1	0	10 (7.6%)
ARI 4	0	1	1	0	2	0	2	2	0	0	0	8 (6%)
ARI 5	3	3	1	3	0	0	1	0	0	0	1	12 (9%)
N	12	12	12	12	12	12	12	12	12	12	12	132 (100%)

ARI, adhesive remnant index; DMSO, dimethyl sulfoxide

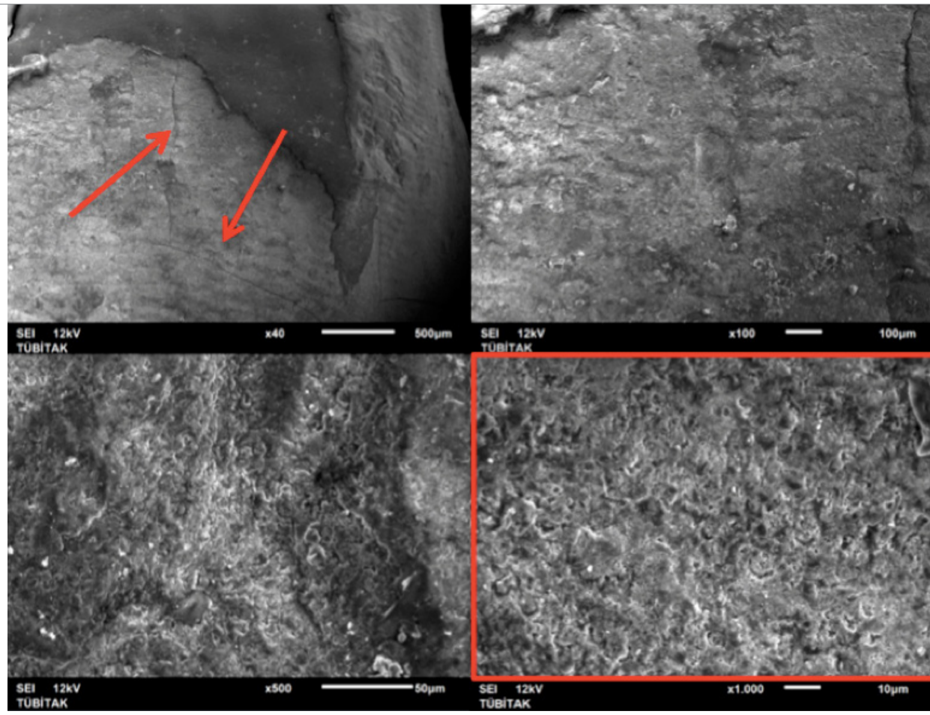

Figure 3. SEM image of group DMSO 15-minutes.
SEM, scanning electron microscopy; DMSO, dimethyl sulfoxide

same age range in the study is important for ensuring that the structures of enamel prisms are similar. It has been reported in the literature that monocrystalline ceramic brackets cause more damage to the enamel than polycrystalline ceramic brackets during the debonding phase.[24] Regarding the bonding types of ceramic brackets, it has been reported that the risk of enamel damage is higher for chemically bonded ceramic brackets.[25,26] In our study, to see the effects of the solutions to be applied clearly, a monocrystalline ceramic bracket type (Pure Sapphire Bracket System, Ortho Technology, West Columbia, US), which can bond to the tooth both chemically and mechanically was preferred. Since we used ceramic brackets in our study, the residual adhesive amount was determined by the modification of ARI scoring.[7,8] For the modification of the ARI scoring, bracket fracture scoring, and enamel fracture scoring was added to the original scoring. In previous studies on the reliability of ARI scoring, it was reported that ARI scores could be evaluated differently for different zoom magnitudes.[27] Therefore, in our study, ARI scoring evaluation was performed twice, with an interval of fifteen days, by the same researcher.

In our study, although the SBS value of the acetone 5-minute and 15-minute groups were lower than that of the control group, the decrease in the group in which only acetone was applied for a long duration (15 min) was found to be statistically significant. Thus, the findings support the hypothesis suggesting that the longer application time of chemical solutions, amplifies their effectiveness. It was found that acetone was the solution that showed the most softening effect on the composite, since the reduction in SBS was lower for acetone groups compared to other chemical solution groups, and this difference was statistically significant. According to the results of our study, we believe that the SBS can be reduced by applying acetone before the debonding of ceramic brackets and it can be an alternative method that will cause less damage to the enamel surface.

In the study of Santana et al.[28], it was reported that the application of acetone and ethanol in addition to the ultrasonic debonding technique did not cause any decrease in the SBS. In the study of Cruickshank and Chadwick[29], ethanol, polyacrylic acid, acetone and acetic acid were applied to anterior composite restorations for 3 min, but the hypothesis that chemical solvents soften the composite was not accepted. However, Wu and McKinney[30] reported that ethanol-dissolved bisphenol a-glycidyl methacrylate was much better than distilled water, and the softening effect of the adhesive increased as the concentration increased. In the literature, it has been stated that polymers with involving more crosslinks can be softened more difficult than polymers with linear structure.[31,32] Depending on the concentration of ethanol and the crosslink densities of the composites, the amount of softening of the adhesive may vary. The hypothesis in the literature that ethanol softens the composite is inconsistent with our results. The highest SBS was observed in the ethanol 5-minute and ethanol 15-minute groups among all groups. No statistically significant difference was found between the short duration and long duration applications of ethanol in terms of softening the composite and reducing the SBS. We believe that this is because the concentration of the agent used, and the application durations are different from those used in other studies.

We observed that the application of DMSO for a short duration (5 min) increased the SBS statistically significantly compared to the SBS of the control group. Thus, it can be said that DMSO is a more effective solvent than ethanol, and less effective than acetone and peppermint oil. We think that due to the high affinity of DMSO to water, the adhesive may harden after application. Although we thought that DMSO would soften the adhesive because it is a good organic solvent while planning our study, it seems that it cannot be a new and alternative method that we can use in the clinic based on the findings we have obtained.

Although Gustiana et al.[19] stated that the solutions should be kept for a long duration, such as 60 min, to observe their full effect, they also reported that short duration applications would be more practical in terms of applications in clinical work practices. In the study of Larmour and Chadwick[17], it was reported that peppermint oil could not be effective for the short duration applications of 1-2 minutes. For this reason, we observed the maximum effects of the solutions by forming groups of short (5 min) and long (15 min) durations in our study. Although there was no statistically significant difference between the short duration and long-duration applications of peppermint oil, its SBS was similar to that of the control group. When compared with other solvents, peppermint oil appears to have the least effect on softening or hardening of the composite. Although we applied each solution for 15 min at the longest to ensure standardization between the groups, the peppermint oil can be applied for a longer duration to observe its real effects; we believe that it can soften the composite with a longer application.

Carter[20] stated that before the debonding of ceramic brackets, patients rinse their mouths with the water (at a safe temperature) supplied from the coffee machine in the clinic so that the adhesive softens, and the brackets can be removed with less damage to the enamel surface. The results of our study do not support Carter's[20] clinical experience. In our study, it was concluded that the short duration and long duration applications of water at 60 °C did not soften the composite, but in contrast, it hardened and increased the SBS statistically significantly. We think that the use of cold water to reduce the SBS should also be evaluated in future studies.

In our study, adhesive fractures were observed in a large percentage of the samples for all groups except the peppermint oil 5-minute group; cohesive fractures were observed for the peppermint oil 5-minute group. From a clinical perspective, the advantage of adhesive fracture is that the cleaning duration can be reduced due to the small amount of residual adhesive on the enamel surface. Thus, less damage will be done to the enamel while cleaning with high-speed rotating tools. Similar to the study of Larmour et al.[18], the percentage of enamel fracture (ARI score 4) was found to be 6% in our study. In studies with ceramic brackets, it has been emphasized that the biggest disadvantage of ceramic brackets is that they cause enamel fractures during debonding.[33,34] In our study, bracket fracture (ARI score 5) was observed with a rate of 9%. Bracket fractures were mostly observed on the occlusal side of the bracket. We believe that this is because the direction of the debonding force is from occlusal to the gingival. Additionally, for monocrystalline ceramic brackets, cracks in Griffith defects, which are the areas where stress is concentrated, can spread and cause fractures in these areas.

Considering the debonding test results, the highest SBS belongs to the ethanol groups among all groups. According to SEM images, it was observed that the most damaging solution to the enamel surface was ethanol. Additionally, although microcracks were observed in all groups, the depth of the cracks was significantly higher in the ethanol group. Based on these results, we think that ethanol is the most damaging solution to the enamel surface and is not suitable for clinical use.

CONCLUSION

Following outcomes can be concluded:

• Ethanol is the most damaging chemical solution to the enamel tissue and is not appropriate for clinical use.

• Acetone application can be used as an alternative method in the clinics to facilitate the debonding of ceramic brackets.

• However, further research is required to determine the techniques and methods that will enable the clinical use of these chemical solutions.

Ethics

Ethics Committee Approval: Ethical committee approval was received from the University of Istanbul Ethics Committee in Istanbul, Turkey (Protocol number: 2019/11, date: February 14, 2019).

Informed Consent: N/A.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - H.U.; Design - S.E.Ö.; Supervision - S.E.Ö.; Materials - H.U. and S.E.Ö.; Data Collection and/or Processing - H.U.; Analysis and/or Interpretation - H.U.; Literature Review - H.U.; Writing - H.U.; Critical Review - S.E.Ö.

Declaration of Interests: The authors have no conflicts of interest to declare.

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Review

Directly Printed Aligner: Aligning with the Future

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Main Points

- 3D technology enabled the inclusion of a digital lab in the orthodontic office.
- Thermoformed aligners is the main way to perform aligner orthodontic treatment.
- Novel aligner resin has been introduced for the direct aligner printing.
- Printed aligners present significant advantages and some disadvantages.
- Studies have been published concerning the properties of the aligners. More studies have to be conducted in order to investigate and optimize printed aligner orthodontic treatment and create a consistent 3D designing and printing workflow.

ABSTRACT

Orthodontics stands on a junction where traditional analog appliance manufacturing slowly but steadily changes to a digital one with the use of 3D technology. The main cause of this shift was the invention and use of computers. The use of computers, computer-aided design (CAD) software, computerized machines, and newly invented materials allowed this change to occur in a relatively short time in dentistry and orthodontics. The trigger for this transformation is the ability to digitally scan the oral cavity. CAD software and 3D printers already existed. It took a few years to include this technology in orthodontics and continuously apply it in the orthodontic office. Orthodontic treatment is mainly based on the use of fixed appliances, while in the last years, thermoformed aligners have been introduced as an alternative whenever a more invisible treatment modality is preferred. Clear aligner treatment is performed using thermoformed aligner. A new aligner resin has been recently invented to allow direct aligner printing. Directly printed aligner possess many advantages compared to thermoformed one. Research has been initiated to investigate all the aspects of the workflow and aligner printing outcome. More studies must be performed to look into the various aspects of directly printed aligners.

Keywords: 3D technology, 3D printing, directly printed aligner, UV curing unit, nitrogen generator

INTRODUCTION

Orthodontics is the only specialty in dentistry and medicine that uses forces to move human body parts, and teeth. The biology of tooth movement is extensively investigated, and theories have been expressed regarding many aspects of this movement. The unique feature of the continuing movement of our teeth throughout our entire life is used to correct orthodontic problems. The main way to move teeth is fixed appliances, which passed a long way since Angle invented the edgewise appliance.

In 1945, a brilliant mind Dr. Kesling[1] introduced a plastic-made appliance called tooth positioner to move teeth without fixed appliances. The positioner was made of rubber on a dental setup and was used immediately after brackets debonding. Later Nahoum[2] evolved an appliance using a two-block appliance for the upper and lower dental arches, while Sheridan et al.[3] in 1993 introduced an Essix appliance to correct minor orthodontic problems combined with the interproximal reduction first used by ML Ballard in 1944.[4,5] The next big step was made four years later when Zia Christi and Kelsey Wirth founded an aligner system called Invisalign (Align Technology, Santa Clara, Calif, USA). Later, other companies followed that path, while in the last years direct-to-consumers aligner was introduced.

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The major shift in aligner production was performed when computer-aided design (CAD) software, 3D printers, and 3D scanning were introduced in Orthodontics. Aligner manufacturing was performed on several plaster models where teeth had to be segmented, removed, and then placed again in the dental model with the use of wax placed to their bases. The introduction of the plaster teeth segmentation concept to the orthodontic CAD software and the continuation of this process using 3D printers to manufacture several dental models converted the analog traditional aligner production to a digital-centered one. There was no need to pour plaster dental models, cut teeth, and reposition them using wax and then vacuum-form aligner anymore. The "clean" computer environment could handle teeth segmentation, and teeth repositioning (setup) in small increments and finally create all the necessary virtual dental models to be printed, which later would be used in the thermoforming procedure. The ability to have a dustless, plasterless, and clean environment, with fewer machines, allowed the installation of a small digital lab in the orthodontic office. Simultaneously, pushed by this impressive 3D technology revolution, companies started creating printing resin materials that were used to print crowns, splints, dental models, and indirect bonding trays (IDB). Unfortunately, this technological evolution brought an uncontrolled use of 3D printers, post-printing units, and hazardous materials in the orthodontic office without the proper installation, which should be guided by approved protocols. The hazards for the patients and personnel are often overlooked, leading to the improper use and installation of the lab in office places where they should not be. Therefore, dental associations should create protocols and guidelines for the correct lab installation, which should be officially checked and approved by government organizations and dental associations.[6]

Due to this immense digital technological advancement, other technologies evolved simultaneously. Resin material for 3D printing was initially only for dental models, while over time, more resins were introduced for occlusal splints, IDB, and lately brackets. Up to this point, aligners were made using plastic foils supplied by various companies in different thickness and made of different materials.

A major evolution in clear aligner treatment was the introduction of the first aligner resin for direct aligner printing. The aligner resin called TC- 85DAC (Graphy, Seoul, Korea) showed up in 2019 and gradually gained ground in the field of aligner production.

Regardless of the current state of directly printed aligner, it seems that the river can go back and that the orthodontist will be able to design and directly print aligner in the office in a self-sufficient environment offering more accurate, easy, fast, and troubleless orthodontic treatments.

Directly Printed Aligner

Credits should be given for inventing the precursors of aligner to Kesling[1], Nahoum[2], and Sheridan[4]. What followed was a natural continuation of the work of those scientists, mixed with the inclusion of digital technology in orthodontics. Invisalign made that big change where 3D technology was mixed, with of artificial intelligence and plastic foil research. Other companies followed serving the same scope, while simultaneously, the in-office concept started showing up, especially with the evolution of 3D printers that became more compact, cheaper, and easy to handle. Software companies realized the in-office aligner production potential and created CAD software exactly for that reason. In the last few years, more and more offices decided to create a small lab at their premises to mainly offer to the patient the option of in-office clear aligner. Posts in social media, webinars, hands-on courses, and conferences dedicated to 3D technology and aligner are a daily phenomenon. Deep inside the orthodontist is excited by the perspective of having a self-sufficient office that is controlled by the orthodontist without the need for an external company to depend on aligner production. Nevertheless, rushing into technology and new materials without research is a phenomenon that is often observed in dentistry and orthodontics. Opposite to medicine, where research comes before drug release, we tend to use machines and materials that are not tested; aligner could not be an exception. On the other hand, the environmental burden from millions of printed dental models and plastic foils, which are not recyclable seems to be overlooked. It is not our intention to criticize the use of aligner but rather to alert the orthodontic community to the possible hazards of the uncontrolled use of non-recyclable materials and the unfortunate trend to use of untested materials and machines.[6]

A solution to the disposal of millions of dental models could be, skipping the dental model printing step. Of course, the ideal solution could be to use a printed aligners that would be recyclable. The ability to directly print aligner which could serve as the next step in aligner treatment is a revolution. The resin called TC-85DAC (Graphy, Seoul, Korea) was the starting point to include directly printed aligner in our armamentarium. At this time, other companies are in the course of releasing their aligner resins too.

Aligner Printing Materials and Units

The workflow for designing thermoformed aligner in the office is more or less known starting from the import of dental scans in dedicated orthodontic CAD software, editing the scans through a procedure, and reaching to the setup where attachments are to be included if needed. From that point, the software designs the models to be printed and later to be used for the aligner thermoforming procedure.[7]

Directly printed aligner designing and printing procedures are different. Essentially the software which is used to design printed aligner is the same as that one for the thermoformed one. The same procedure is followed to reach the setup and attachment virtual placement. Following the setup, the operator must virtually design, at the initial malocclusion model, the aligner that will be used by the software to create all the rest of the aligner (Figure 1). Software available for printed aligner are Deltaface (Coruo, Limoges, France) and Maestro (New Age, Pisa, Italy). A unique feature of the Deltaface software is that it allows the thickening of the aligner in specific areas, where the operator wants to have a stiffer part. For instance, in case there is a need to move a lower central incisor labially the software, following a command, thickens the aligner at the palatal side of the aligner according to the millimetric value that the operator chooses (Figure 2). The new protocol of the aligner design proposes a uniform thickness of 0.5 mm for a week of wearing and 0.7 mm for 10 days of wearing. The aligners are designed and exported from the software as "Standard Tessellation Language" (STL) files. To print the aligner, 3D printers are needed, which fall into the category of VAT technology called also Stereolithography (SLA). Currently, there are three categories of VAT printers: SLA, Direct Light Projection (DLP), and masked SLA or LCD.[7] All of them can be used but the most frequently used are the DLP. Each printer has its software for printing with different tools and ways of support positioning. Supports are essential for successful and accurate printing and should be positioned in the needed areas (it is done automatically). The aligner can be positioned horizontally or vertically on the virtual printer platform. Positioning them horizontally increases the speed of printing due to fewer layers that must be printed but with the disadvantage of more supports. Additionally, less number of aligners can be printed each time. Vertically positioned aligners will be printed more slowly, with fewer supports, while more aligners can be printed immediately but with a higher chance of errors due to the increased number of layers to be printed (Figure 3). The z-axis resolution for printing used is 100 μm, which ensures adequate printing accuracy. The resin to be used must be homogenous, so stirring for some minutes is essential, while the temperature of the resin has to be around 30 °C, otherwise there will be a possibility of failure. When printing is finished, the aligner is removed from the printer's platform and placed in a centrifugation machine with their internal parts facing the outside to remove the excess uncured resin (Figure 4). Centrifugation should take approximately 5-6 minutes with a 500-600 rpm. The next step is to remove the supports and cure the aligner in the dedicated UV curing unit called Tera Harz (Graphy, Korea, Seoul) (Figure 5). The curing unit is manufactured especially for printed aligner with high-intensity

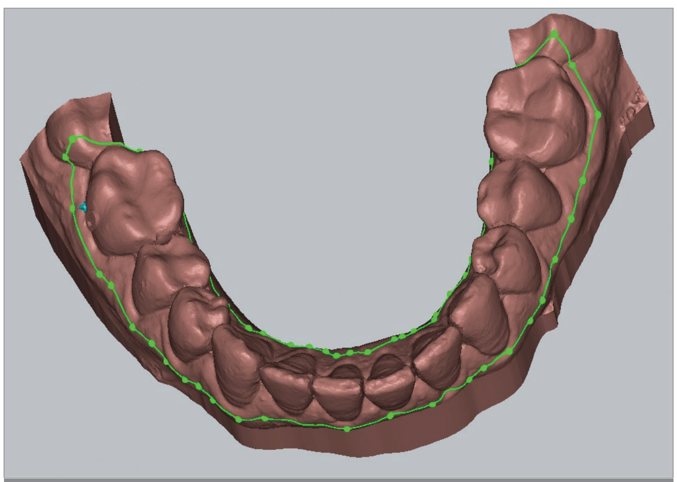

Figure 1. Directly printed aligner virtual design in Brackets software. Thickness can also be adjusted in the printed aligner module

Figure 2. Brackets software enables the clinician to increase the aligner thickness in specific areas where teeth movement occurs. The software detects the areas where movement occurs and adds the extra predetermined material. Note the increased thickness of the aligner at the lingual side of 42 and 31which is planned to be moved labially

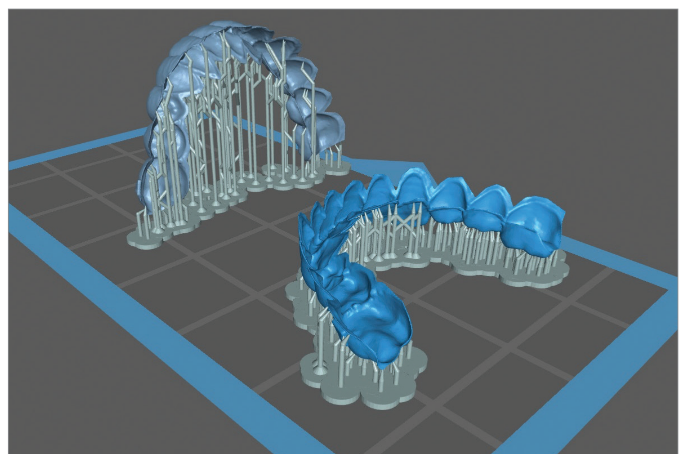

Figure 3. Virtual positioning of the aligner in a vertical and horizontal orientation. Horizontal positioning has the advantage of faster printing, but fewer aligner can be printed each time and more supports are needed. Vertically positioned aligner have the disadvantage of slower printing, but more aligner can be printed each time with the need of fewer supports

Figure 4. Vertically printed aligner with their supports. Note the yellow color which turns transparent after UV curing

leds and is equipped with a nitrogen generator to ensure curing without the presence of oxygen. Oxygen is a factor that inhibits complete polymerization, which could create problems with the mechanical properties of the aligner.[8] Complete polymerization ensures the production of a fully biocompatible aligner while transparency is also enhanced. Following curing, the aligner is polished at the areas where the supports used to be. In the end, the aligner is immersed in hot water for a few seconds to remove any possible remnants of substances that could create problems for the patient.

Clinical and Research Consequences

Printed Aligner Studies and Considerations

As mentioned before, in dentistry we tend to rush and use materials and machines without the proper research while medicine works exactly the opposite way. The nature of the 3D technology, the multistep, sensitive to error procedures, and the use of new materials call for research to create safe and efficient orthodontic appliances. Printed aligners fall into this category where research should be undertaken.

Printed aligners are new appliances that need to be tested both *in vitro* and *in vivo*. The first attempt to study the mechanical properties of printed aligners was done by Can et al.[9] where the effects of *in vivo* aging on their mechanical properties were studied. At that time, the protocol that the aligner was printed was the initial with a regular curing unit and with oxygen presence. Nevertheless, at the end of 1 week of wearing, the mechanical properties of the aligner were lost at an insignificant percentage, while a similar study on Invisalign aligner showed that almost half of the mechanical properties of the aligner were lost after 1 week of use.[10]

Figure 5. Tera Harz UV curing with a nitrogen generator that allows an oxygen-free polymerization

Additive manufacturing or 3D printing as it is known, is a multi-step procedure where each stage should be carefully carried out to ensure a successful printing outcome. Especially in the case of printed aligners, consistent workflow will ultimately lead to consistent results with consistently good quality aligners. The unique feature of printed aligners that differentiates them from other printed objects or appliances is that they are the only active appliances, made to exert force on teeth. All other printed appliances such as occlusal splints, IDB trays, and even brackets, do not exert force. Brackets do not directly exert forces but rather they are the means by which forces from the archwires pass to the teeth.

An important factor that could definitely lead to aligner defects or printing failures is the quality of the 3D aligner file upon exporting. According to the author's experience, even from the same software, aligner files could be of different quality. Even more, different software use could create different quality 3D aligner files even for the same patient. Corrupted files, defects on the aligner mesh, or other problems could lead to problems in the structure of the aligner or printing failures.

At the next step where the aligner is positioned on the printer's platform, a question arises whether printing in a horizontal position creates aligner with different mechanical properties compared to vertically positioned aligner. Transparency could also be different since the horizontally printed aligner consists of fewer layers while vertically printed much more. The roughness of the aligner is another factor to be examined. More layers, that are present at the vertically printed aligner, could contribute to the creation of a rougher surface, which could be aggravated by the *in vivo* aging of the aligner. A study concerning the comparison of the mechanical properties between vertically and horizontally printed aligner has already been conducted.

In a recent study by Zinelis et al.[11], was proved that different 3D printers create aligner with different mechanical properties. This finding is critical as it is determining the quality of the aligner that will affect the ability of the aligner to move teeth efficiently and predictably. Each printer uses different technology to polymerize the resin either using a beam of laser, light projector, or led. Other important parameters known as "irradiant exposure conditions" that include power and exposure time/velocity might play a role in the difference between the printing outcomes. LED printers in this study provided better mechanical properties (i.e., hardness) to the aligner, which are significant from a clinical standpoint. Despite the findings, there is not yet any evidence that the significant mechanical properties found affect the clinical efficacy of orthodontic therapy.

Another factor that should be investigated is the possibility that the same printer could print the same aligner file in repeated printing sessions with different mechanical properties. Intravariability printing examination is critical as it will prove the printer's ability to accurately print the same aligner every time having the same mechanical properties.

The next step after printing is centrifugation for 5-6 minutes at 500-600 rpm. The reason for that is to ensure that excess uncured resin is entirely removed. Failure to do so might lead to excess resin curing and bad fitting of the aligner due to the increased internal thickness of the aligner. Immediately after printing, aligner is yellow, sticky, and very soft with a shape memory property. UV curing that follows centrifugation is the one to give the final properties to the aligner. It is possible that centrifugation could alter the shape and fitting of the aligner. Therefore, it is essential to investigate the effect of centrifugation on the aligner as accurate fitting is critical for aligner treatment.

The last and one of the most important stages in the whole workflow is the UV curing of the aligner. UV curing units can be found in the market with different led power intensities and other functions. UV curing polymerizes the outer shell of the aligner, which is always not fully polymerized after printing. As mentioned before, the only active appliance that exerts a force on teeth and is manufactured by the 3D printing process is the printed aligner. For this reason, UV curing should be complete to ensure that all potential properties of the aligner will be expressed. Initially, Graphy released a UV curing unit called Cure M, which was dedicated to the curing of aligner. It seems that following company research, the printed aligner was not ideal concerning its properties. It is well known that oxygen inhibits the full polymerization of oligomers and monomers to polymers.[8] For this reason, a free-oxygen environment is desirable to ensure that the aligner will be fully polymerized. A new UV curing unit recently released called Tera Harz includes a more sophisticated technology where a nitrogen generator connected to a high-pressure (5-6 bars) air connection compresses nitrogen into the curing chamber of the unit. Resins, as it is stated also at the leaflets of the liquid, are toxic, irritating, and allergic. In this pre-polymerization state, they are certainly not biocompatible. Resins gain their biocompatibility at the printing stage but mostly at the UV curing stage. Incomplete polymerization is a factor that possibly initiate irritation or even allergic reactions to the patient. Therefore, leaching of materials in an incompletely cured aligner should be taken seriously. For this reason, complete polymerization, and the inclusion of a nitrogen generator in the curing unit is essential. Apart from the biocompatibility perspective, complete polymerization could be a contributing factor in creating adequate aligner transparency, which will be kept high until the end, decreased roughness after *in vivo* aging, and better mechanical properties. All these hypotheses should be tested using scientific research.

The resin manufacturing company states that after UV curing and aligner polishing, the aligner should be placed in hot water for a few seconds. Although it is not proven scientifically, they claim that it might remove remnants of particles on the aligner surface that could cause reactions to the patient's oral cavity. Additionally, the immersion of the aligner in hot water before placing it into the patient's mouth instantly transforms the aligner into a very soft object that can be immediately placed into the teeth of the patient with easiness. Again, at this point, the change in the mechanical properties of the aligner before and after the immersion in hot water should be scientifically investigated.

Aligner fitting is one of the most important factors that determine the treatment outcome. It was shown in aligner studies that aligner tend to have a distance from the surface of the teeth, which affects their ability to perform teeth movements.[12] For example, in cases of round-shaped teeth where rotations should be performed, the above issue could lead to loss of tracking and failure to derotate the teeth. In the same study, Koenig et al.[12] compared two thermoformed aligner and one printed aligner in terms of accurate fitting. The study presented better accuracy for the printed aligner compared to the two thermoformed aligner. The physical properties of the printed aligner were found to have lower yield strength and elastic moduli compared to conventional PETG. The initial force for stress relaxation (which is one of the most important properties of aligners) under high temperature (80 °C) was 18N, but for 1% elongation, the residual static force was greatly reduced to about 1N. An interesting finding for repeated loads, stress relaxation decreased and residual static force increased. Nevertheless, due to the multi-step inconsistent printing workflow, in another printing instance, fitting could be different.

Another unique feature of aligner in general is that they are the only orthodontic appliances that are renewed every 1 or 2 weeks, depending on the protocol. This feature is of great importance for the patient's safety. Renewal of aligner means that every time the aligner changes new increased chemical substances amount could be released in the mouth. In the case where the aligner is not fully tested for material leaching or where the aligner is proved to release chemical substances, the effect on the patient could be damaging. We could think of it as taking every week an amount of the same medicine that is harmful to the human being. For this reason, as mentioned before, a thorough *in vitro* and *in vivo* investigation should be carried out before the material release.

Cytotoxicity is defined as the toxicity caused due to the action of materials on living cells. To exclude the possibility of cytotoxicity of the aligner to human cells, a study was recently conducted by Pratsinis et al.[13] Aligner was immersed in sterile deionized water for 14 days. The cytotoxicity of the released factors was assessed by MTT assays (solvent) on human fibroblasts. The authors concluded that if there were any factors released, those were not found to be cytotoxic.

A major issue regarding material release in our days is the release of bisphenol-A (BPA), which is found in dental materials (composites). BPA is a substance that is accused to cause estrogenicity, which is the action of endocrine-disrupting chemicals that mimic, block, or interfere with hormones in the body's endocrine system. Apart from dental materials, plastic has been accused of BPA release. BPA generally creates problems for males but also other problems for both genders such as type 2 diabetes, obesity, growth inhibition, behavioral changes, cardiovascular diseases, and certain types of cancer.[14-16] Composite attachments that are widely used in aligner treatments and which are designed in block-like different shapes seem to be an issue taking into account that often they are used in almost every tooth and that in refinements, they are removed and then repositioned.[17] An ideal evolution of the aligner is to be able to move the teeth without the need for composite attachments. In the same study where cytotoxicity was investigated, estrogenicity was also examined showing no estrogenicity signs.[13]

A study performed to investigate the possible release of urethane (UDMA monomer) by the aligner presented the release of this monomer.[18] The repeated intraoral exposure to this substance due to the weekly renewal of the aligner could have potential health hazards for the patient. Previous studies have shown that urethane could induce cytotoxicity in human dental pulp cells. Nevertheless, this could not be justified in this study.[19,20]

Surface roughness was assessed for printed aligner compared with Invisalign appliances. The findings showed an increased surface roughness for the printed aligner compared to Invisalign both for the control group (unused) and the used ones.[21] Increased roughness could lead to aligner discoloration or pigmentation increases the accumulation of plaque and increased material leaching.[22,23]

Advantages and Disadvantages of Printed Aligners

Even though printed aligners have just appeared in the orthodontic field, they possess some advantages compared to thermoformed. With the proper and targeted research, printed aligners could displace thermoformed aligners allowing for better, more efficient, safer, and faster orthodontic treatments.

1. The environmental burden is an issue that concerns all humanity. Materials that are not recyclable, burden nature leading to problems for all living beings on the planet. From the time when dental models are made, and following 3D printing, the planet experiences a slow, silent gathering of millions of non-recyclable printed models every year. Printed aligner could be a solution since no dental models are needed. Ideally, a printed aligner could be recyclable. In this way, this could be another advantage compared to thermoformed one.

2. Since the steps of model printing and thermoforming procedure, aligner removal, and trimming are excluded from the procedure, direct aligner printing is a faster procedure. For instance, in cases where the orthodontist would like to instantly deliver aligner printing in a horizontal orientation would allow the fast delivery of the aligner/s to the patient.

3. The thermoforming procedure entails the use of units (handpiece) to remove the aligner from the dental model. Additionally, the aligner must be polished at their extremities. All this process creates a cloud of dust that creates a dirty office environment but also entails hazards for the operating personnel. Printed aligners are manufactured in a dust-free environment, which is advantageous for both the office and personnel.

4. According to a Koenig et al.[12], printed aligners exhibit higher fitting accuracy compared to two commercially available plastic foils that were tested and which are often used in our orthodontic offices. Fitting accuracy is indeed one of the biggest problems of aligner. The loss of tracking and inability to move teeth, for example in, rounded-shape teeth, is due to bad fitting.

5. A major advantage of printed aligner is the ability to print aligner with uniform thickness. Uniform thickness has the advantage of delivering uniform forces to all teeth. According to a study by Koenig et al.[12], there was a thickening of 12% of printed aligner, while thermoformed aligner had a significant decrease in thickness. Another study showed that thermoformed aligners have less thickness after the thermoforming procedure compared to the initially used plastic foil.[24]

Lee et al.[25] performed thermal deformation of the aligner foil in a standardized block model. They reported a thickness change of 54% or more through this process. At the thermal deformation, shrinkage and expansion of the material may occur, which results in a difference in the thickness of each different tooth. Such morphological variation can be a problem in our effort to improve our clinical results in tooth movement.[26]

6. Foils for a thermoforming process come in a specific thickness. Thus, they cannot be intentionally altered. In contrast to the thermoformed, printed aligners are more versatile in allowing increasing the aligner thickness in specific areas. Deltaface CAD software includes a command tool where the software detects the teeth' movements and applies the selected extra thickness to those areas. In this way, the operator selects the overall thickness of the aligner and then by selecting variable thickness sets the value of the extra thickness needed. Upon aligner design, the software automatically adds the extra thickness only on areas where teeth are being moved. For instance, in the case of labial lower incisor movement, the software adds material to the lingual part of the incisor (Figure 2). The added thickness increased the stiffness of the aligner at that point. Nevertheless, it is not scientifically proven that increased thickness could have a favorable effect on the efficacy of aligner treatment. Added thickness could be added by the software on the occlusal surfaces of posterior teeth if an open bite needs to be corrected (Figure 6). In the same way, aligner thickness could be increased on the palatal side of the upper incisors in cases of deep bites (Figure 7).

7. 4D printing is the next step of the technology of 3D Printing that was invented by Hull[27] in 1984, which introduces time as the fourth dimension. Smart material printing is another name of 4D printing. Smart materials reconstruct the shape or action of a printed object in response to external stimuli such

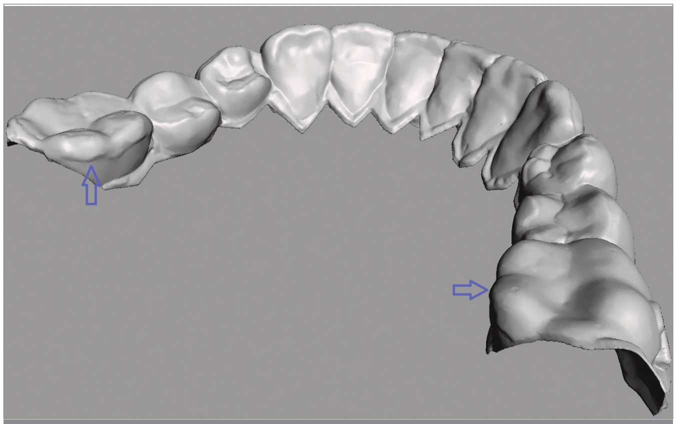

Figure 6. In cases of open bite, the orthodontist can choose to increase the thickness of the aligner at the molars to facilitate bite closure

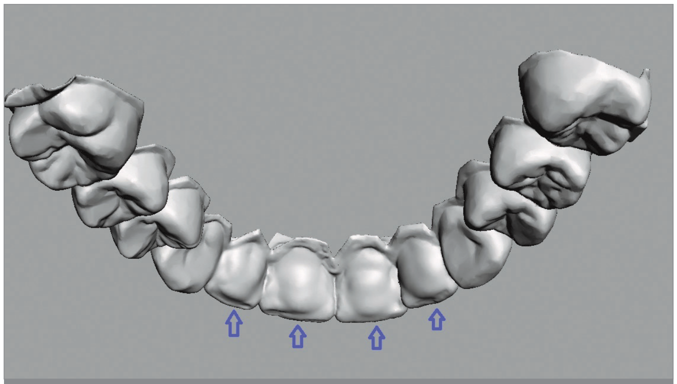

Figure 7. In cases of deep bite, the orthodontist can increase the thickness of the palatal side of the upper incisors to correct the deep bite.

as mechanical, electrical, chemical, or thermal over time.[28] A resin with smart material properties could be the solution to problems such as loss of tracking in tooth movement, excessive use of attachments, etc. For instance, the resin could be sensitive to a specific wavelength light cure, and its action and application on specific aligner areas could change the amount or duration of force delivery.

Usually, new technologies also present some disadvantages that over time are reduced. For example, a major disadvantage is the fact that the whole printing and post-printing procedure is inconsistent and depends on multiple steps. An error in one step affects the following stages and can create problems. For this reason through extensive research, a scientific evidence-based protocol should be conducted, which will allow a consistent and high-quality outcome. Another disadvantage is the somewhat higher cost of equipment compared to the thermoformed aligner production. Apart from the software that exists in both kinds of aligner, a printer should be purchased together with a UV curing unit. Of course, one should not forget that there is no need for a thermoforming unit that has a price equal to a descent 3D printer. One should also calculate the number of aligner that can be printed per ml and the price of each thermoformed aligner that is created. This should include the price of the plastic foil and the 3D-printed- model that is needed.

CONCLUSION

3D printing has introduced a new way of designing and manufacturing appliances. Orthodontic treatment due to this technology can become more efficient, easier, faster, and with fewer problems for the patient. Aligner in their thermoformed form have gained a relatively big piece of the overall orthodontic treatment appliances. Nevertheless, their ability in correcting orthodontic problems is questioned, especially in specific types of teeth movements. Printed aligner seem to be a new aligner treatment modality that could solve the problems that arise from the use of aligner. The advantages of printed aligner that were mentioned before compared to the thermoformed ones are enough to motivate companies to invent new aligner resins and evolve them to try reaching the efficacy of fixed appliances. Mechanical properties must be optimized to have printed aligner equal to or even better compared to the existing thermoformed aligner. Safety is another issue that must be addressed and solved, although studies have shown that at least the specific printed aligner are safe to use. Due to the release of materials from aligner that are renewed every 1-2 weeks, and which are not easy to be detected (studies are targeted to detect specific released materials), there is a necessity to create a material that will be changed less often (i.e., every 1-1/2 months). This could help decrease the amount of material released by the aligner and increase the safety level in aligner treatment. Of course, the invention of such material should be accompanied by better mechanical properties, which will not be affected by prolonged aligner use, while aligner transparency should be kept high for aesthetic reasons. Smart materials are already been used in engineering and proof-of-concept experiments. The next step is to use this technology in the orthodontic field, which will be advantageous for our orthodontic treatments. The in-office concept is here to stay. Nevertheless, orthodontic and dental associations should create protocols and guidelines for digital laboratory installments in orthodontic offices. The observed uncontrolled installation of 3D printers, post-printing units, and toxic and irritating materials in orthodontic offices should be controlled through protocols that will be applied and often checked by dental associations. Scientific studies should be conducted before the release of new materials and technologies resembling the medicine way.

Ethics

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Systematic Review

Gingival Biotype and Its Relation with Malocclusion

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Main Points

- No relationship was observed between Angle's classification of malocclusion and the Gingival Biotype (GT)
- Keratinized gingival width was narrow among individuals with thin GT.
- Definitive relationship between GT among individuals with severe crowding cannot be established.
- Medium followed by thin GT was prevalent among individuals with pro-inclination of incisors.

ABSTRACT

Objective: To systematically review the relationship between gingival biotype (GT) and malocclusion.

Methods: The review followed PRISMA standards of quality for systematic reviews and meta-analyses reporting with PROSPERO registration number CRD42020126543. The systematic database search included MEDLINE, Scopus, Embase, PsychINFO, CINAHL, and other key journals; the article search was performed until February 2020. Cochrane's risk of bias in non-randomized studies-of interventions (ROBINS-I) was used to grade the methodological quality of the included studies.

Results: The systematic search identified 105 studies, six studies satisfied the inclusion criteria for eligibility. The study participants ranged from 26 to 200 (total n=812), with a mean of 135. Study participants were aged between 14 and 32 years. Five studies were graded as the moderate risk of bias and one study as low risk of bias. Two studies showed thin GT among individuals with severe crowding compared to mild crowding. Three studies showed a thin GT with a narrow zone of the keratinized gingival width compared to a thick GT. No relationship was found between GT and Angle's classification of malocclusion.

Conclusion: No relationship was observed between Angle's classification of malocclusion and GT. Thin GT was prevalent among individuals with pro-inclination of incisors. Keratinized gingival width was narrow among individuals with thin GT.

Keywords: Systematic review, Gingival biotype, malocclusion, width of keratinized gingiva

INTRODUCTION

Gingival biotype (GT) refers to different characteristics and thickness of gingiva in the buccolingual dimension.[1] They are categorized into different types depending upon their thickness as a thin, medium, thick, or very thick.[1,2] The quantitative differences in the gingival thickness are important because they respond differently to inflammation and surgical insult, which further influences the prognosis of the treatment.[1-3] In clinical practice, proper diagnosis of the GT is central to the decision making because it affects the outcome of periodontal therapy, orthodontic tooth movement, implant treatment, and root coverage procedures.[4,5] Many factors contribute to differences in GT like age, gender, tooth morphology, tooth position, growth type, and genetics.[3] GT plays a critical role during the orthodontic movement of the tooth because teeth with thin biotype are more prone to gingival recession and soft tissue defects compared to thick biotypes.[6,7] The literature suggests that the gingival recession

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is a common anecdotal observation in periodontal - orthodontic interrelation.[6-8] Experimental evidence suggest that orthodontic tooth movement creates an environment favorable for plaque accumulation around the appliances leading to gingival inflammation and periodontal breakdown.[9,10] However, the root movement within the alveolar housing may lead to dehiscence, gingival recession, and root exposure.[9] Hence, the pre-treatment evaluation of the quantitative differences in the biotype should be considered as a factor that influences the successful outcome in root coverage procedures, implant restoration, and orthodontic treatment.[4,5,10] Previously authors have studied the correlation between GT and different types of malocclusion.[1,11-15] When the authors searched for the literature, could not find any systematic review, which assessed the relationship between GT and malocclusion. Therefore, the present systematic review was conducted with the aim of identifying the relationship between GT and malocclusion.

METHODS

The planning, conduct, and reporting of this systematic review follows PRISMA standards of quality for reporting systematic reviews and meta-analyses with register number CRD42020126543.[16] Approval from the Institutional Review Board was not required.

Questions

The area of focus was to examine the GTs in different dental malocclusion. The research question was defined according to the PICO format as follows:

P (Population/Patients): Original studies in human subjects with permanent teeth having skeletal or dental malocclusion.

I (Intervention): Subjects not undergoing any orthodontic treatment, only the descriptive studies with measurement of GTs among individuals with malocclusion.

C (comparison): GT in subjects with normal occlusion were compared with GTs in subjects with malocclusion.

O (Outcome): Measurement of GTs (thick, thin, mean thickness), the width of keratinized gingiva (WKG).

Study Eligibility

Research published in the English language that investigated the different types of GTs in permanent teeth among individuals with malocclusion were included in the study. The subjects were not undergoing any orthodontic intervention. The editorial letter, case reports, in vitro studies, and studies not investigating the types of GTs in permanent teeth were excluded at this stage.

Study Identification

The scientific database search included, Cochrane library (Cochrane review, Trails), Embase, MEDLINE (PubMed, OVID Medline, and Ebsco), Web of Knowledge (Social science, conference abstract), SCOPUS, CINAHL (Nursing and allied health), PsycInfo (Psychology and psychiatry), ERIC (Education) using key terms focused on the specific search strategy (malocclusion, skeletal, occlusion, Class I, Class II, Class III, gingival, biotypes, periodontal, morphotypes, thickness, associations, prevalence, dimensions, changes, evaluation). Besides, four key orthodontic journals (American Journal of Orthodontics and Dentofacial Orthopedics, Angle Orthodontics, European Journal of Orthodontics, and Journal of Clinical Orthodontics) and two periodontal journals (Journal of Periodontology and Journal of Clinical Periodontology) were searched for relevant articles. The research publications until February 2020 were searched. Any additional studies meeting the inclusion criteria were identified from the reference lists of all included articles.

Study Selection

The inclusion of studies was by screening all titles and abstracts independently and in duplicate. The intra-class correlation coefficient of 0.84 was achieved in inter-rater agreement for study inclusion. The Conflicts between the two reviewers were resolved through consensus discussion.

Risk of Bias Assessment

Cochrane's tool of risk of bias in non-randomized studies - of interventions (ROBINS-I)[17] was used to assess the risk of bias. Each domain is graded as a low risk of bias, moderate risk of bias, serious risk of bias, critical risk of bias, or no information.

Data Extraction and Data Synthesis

Two reviewers extracted the data independently using a data extraction sheet. Discrepancies between the reviewers were resolved by consensus through discussion. The following data were extracted from each included study: first author, year of publication, the type of study, study quality, sample size, inclusion criteria, treatment type, malocclusion type, measurement criteria, GTs, dimensions, statistical analysis used, and the conclusions by the authors.

RESULTS

Trail Flow

The search strategy identified 98 articles, with an additional seven identified from a review of references and screening of key journal indices. Of these, six articles were identified by the authors for inclusion in this systematic review (Figure 1).

Study Quality

Five studies were graded as a moderate risk of bias and one study as low risk of bias (Table 1). The data were available from 2012 to 2020.

Study characteristics in relation to age, gender, ethnicity, diagnostic criteria, and the type of malocclusion used.

The number of study participants ranged from 26 to 200 (total n=812, male=340, female=472), with a mean of 135. The study participants were aged 14 to 32 years. Two of the included studies were conducted in Saudi Arabia, two in Turkey, one in China, and one in Italy (Table 2). Three of the included studies used trans-gingival probing to measure the GT and three studies used periodontal probing. Four studies (Matarese et al.[1], Alkan et al.[11], Kaya et al.[13], Zawawi et al.[14]) considered Angle's classification of malocclusion, Jing et al.[12] used skeletal malocclusion, and Zawawi and Al-Zahrani[15] measured GT in inclined or protruded incisors (Table 3).

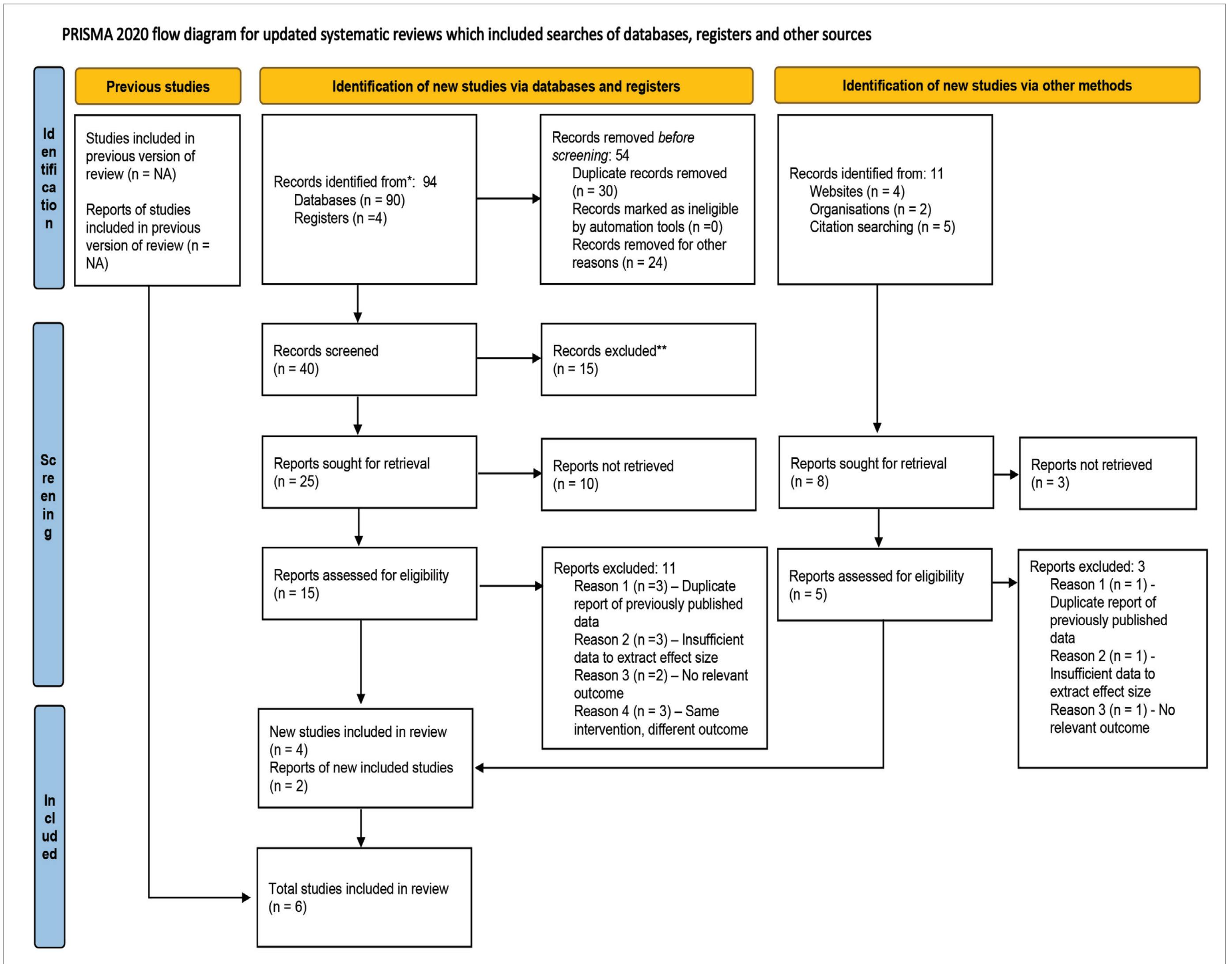

Figure 1. Study selection flow diagram of systematic review

Table 1. Risk of bias assessment of included studies using Cochrane's risk of bias in non-randomized studies - of interventions (ROBINS-I)

ROBINS-I criteria	Author/Year					
	Jing et al.[12] (2019)	Alkan et al.[11] (2018)	Kaya et al.[13] (2017)	Matarese et al.[1] (2016)	Zawawi and Al-Zahrani[15] (2014)	Zawawi et al.[14] (2012)
BC	L	L	L	L	L	L
BSP	L	L	L	L	L	L
BCI	S	L	M	L	S	L
BDI	M	M	L	M	M	M
BMD	M	M	L	L	M	M
BMO	M	L	L	M	M	L
BSR	L	L	L	M	L	L
Overall score	M	M	L	M	M	M

BC, Bias due to confounding; BSP, Bias in selection; BCI, Bias in classification of interventions; BDI, Bias due to deviations from intended interventions; BMD, Bias due to missing data; BMO, Bias in measurement of the outcomes; BSR, Bias in selection of the reported result; L, Low risk of bias; M, Moderate risk of bias; S, Serious risk of bias.

Table 2. Descriptive data of the included studies

Author/Year	Study type	Inclusion criteria	Population studied	Sample size (Male/ Female), mean age (range) in years	Statistical analysis used	Authors conclusion
Jing et al.[12] (2019)	Cross-sectional	Periodontally (PD ≥5 mm) and systemically healthy subjects with skeletal Class III malocclusion	China	26 (9/17) 23.29 ± 3.71 years	Analysis of variance (ANOVA) and chi-square test	Significant correlation between WKG and GT. Higher prevalence of thick GT in maxillary anterior teeth compared to mandibular teeth
Alkan et al.[11] (2018)	Cross-sectional	Periodontally (PD ≥4 mm) and systemically healthy subjects	Turkey	181 (63/118) Male 15.8 ± 2.6 years Females 17.3 ± 3.9 years	Factorial variance analysis and chi-square test	No significant relationship of WKG and the mean GT according to the Angle classification
Kaya et al.[13] (2017)	Cross-sectional	Systemically and periodontally healthy subjects (Free from attachment loss and PD <4 mm) with complete permanent dentition	Turkey	187 (66/121) Less than 29 years	Factorial variance analysis and chi-square test	No significant relationship of WKG and the mean GT according to the Angle classification
Matarese et al.[1] (2016)	Cross-sectional	Systemically and periodontally healthy	Italy	76 (38/38) Age-14.7 years	Student's t-test and the chi-square test	Prevalence of thick gingival biotype in patient with Class II malocclusion and a slight prevalence of thin gingival biotype in patient with Class I malocclusion. Difference not statistically significant
Zawawi and Al-Zahrani[15] (2014)	Cross-sectional	Systemically and Periodontally healthy subjects with age more than 18 years	Saudi Arabia	142 (64/78) 26.56 ± 2.55	Student's t-test and chi-square test	A high prevalence of thin GT in proclined and protrused mandibular anterior teeth
Zawawi et al.[14] (2012)	Cross-sectional	Systemically and Periodontally healthy subjects with age more than 18 years	Saudi Arabia	200 (100/100) Male -32.4 ± 11.0 years Female- 31.7 ± 11.1 years	Student's t-test and chi-square test	A high prevalence of thin GT among females and smokers had thicker GT. No relationship was found between GT and Angle's classification of malocclusion.

WKG, Width of keratinized gingiva; MGJ, Muco gingival junction; GT, Gingival biotype; PD, Probing depth.

The type of GT according to malocclusion type and WKG: Jing et al.[12] showed 72.5% to 96.2% thick GT in maxillary teeth and 44.2% to 47.1% thick GT in mandibular teeth (p=0.001). The WKG was 4.88 mm to 5.59 mm in maxillary teeth and 3.02 mm to 3.68 mm in mandibular teeth. Alkan et al.[11] showed 11.6% of thin GT in subjects with Class II malocclusion, 12.7% in Class I, and 5.5% in Class III malocclusion (p=0.895). Subjects with severe crowding presented with 12.7% thin GT (p=0.794). Kaya et al.[13] showed a mean GT of 0.73 ± 0.17 mm in Class I occlusion and 0.66 ± 0.7 mm in Class III occlusion (p=0.140). Severe crowding subjects presented with a mean GT of 0.71 ± 0.16 mm (p=0.321). Matarese et al.[1] showed 34.9% prevalence of thick GT in Class I occlusions and 32.6% thick GT in Class II and Class III occlusions (p=0.143). Zawawi et al.[14] showed 57.1% prevalence of thick GT in Class I occlusion, 55.9% thick GT in Class II, and 46.2% thick GT in Class III occlusion (p=0.6) (Table 4).

Table 3. Data regarding the gingival biotypes, method of assessment, dimensions

Author	Tooth type/ number of teeth examined	Criteria's assessed	Definitions of assessment method for WKG	Gingival biotype measurement	Malocclusion type	Tooth dimensions analysis
Jing et al.[12]	Maxillary and mandibular anterior teeth	PI, GR, WKG, GT, BI, PD	WKG from MGJ to the FGM at the mid buccal aspect of the tooth and dental arch	Periodontal probing. Transparency of FGM while probing the sulcus at the mid facial aspect of tooth. Thin GT when the underlying periodontal probe can be seen through the gingiva; otherwise, it was considered thick.	Skeletal Class III malocclusion with ANB ≤-5 degrees	NA
Alkan et al.[11]	Maxillary anterior teeth	GI, PI, PD, WKG, GT	WKG from MGJ to the FGM	TGP using digital caliper with a sensitivity of 0.01 mm. Apical to the FGM and coronal to the MGJ. Mean of GT less than 1 mm=Thin biotype. More than 1 mm=Thick biotype	Angles Class I, Class II and Class III	Space analysis for crowding: mild (0-3 mm), moderate (4-6 mm), and severe (>6 mm).
Kaya et al.[13]	Mandibular anterior teeth	GI, PI, PD, WKG, Crowding	WKG from MGJ to the FGM at the buccal area of the mandibular anterior teeth	TGP using digital caliper with a sensitivity of 0.01 mm. Apical to the FGM and coronal to the MGJ. Mean of GT less than 1 mm=Thin biotype. More than 1 mm=Thick biotype	Angles Class I, Class II and Class III	Space analysis for crowding: mild (0-3 mm), moderate (4-6 mm), and severe (>6 mm).
Matarese et al.[1]	Mandibular anterior teeth	NA	NA	TGP using translucence of a periodontal probe UNC 15. Thin GT when the underlying periodontal probe can be seen through the gingiva; otherwise, it was considered thick.	Angles Class I, Class II and Class III	NA
Zawawi and Al-Zahrani[15]	Maxillary and mandibular incisor teeth	GT	NA	Periodontal probing. Transparency of FGM while probing the sulcus at the mid facial aspect of incisors. Thin GT when the underlying periodontal probe can be seen through the gingiva; otherwise, it was considered thick.	Inclined or protrude incisors	Inclination (proclination/ retroclination) and position (protrusion/retrosion) of the maxillary and mandibular incisors were assessed on lateral cephalometric radiographs
Zawawi et al.[14]	Maxillary anterior teeth	GT	NA	Periodontal probing. Transparency of FGM while probing the sulcus at the mid facial aspect of both maxillary central incisors. Thin GT when the underlying periodontal probe can be seen through the gingiva; otherwise, it was considered thick.	Angles Class I, Class II and Class III	NA

GI, Gingival index; PI, Plaque index; BI, Bleeding index; PD, Probing depth of periodontal pockets; WKG, Width of keratinized gingiva; MGJ, Muco gingival junction; FGM, Free gingival margin; GT, Gingival biotype; TGP, Trans gingival probing; NA, Not available.

Table 4. Outcomes of the included studies

Author			GT (mean or % prevalence)	WKG (mean or % prevalence)	p value
Jing et al.[12]	Maxillary teeth		Thick GT- 72.5% to 96.2%	4.88 mm to 5.59 mm	0.001
	Mandibular teeth		Thick GT- 44.2% to 47.1%	3.02 mm to 3.68 mm	
Alkan et al.[11]	Class I		Thin - 21 (11.6%) Thick - 50 (27.6%)	4.9 ± 1.7 to 7.3 ± 2.1 mm	
	Class II		Thin - 23 (12.7%) Thick - 57 (31.5%)	4.02 ± 2.2 to 7.2 ± 1.9 mm	0.895
	Class III		Thin - 10 (5.5%) Thick - 20 (11%)	4.7 ± 1.6 to 6.4 ± 2.5 mm	
	Mild crowding		Thin - 18 (9.9%) Thick- 39 (21.5%)	3.1 ± 1.5 to 7.4 ± 2.6 mm	
	Moderate crowding		Thin - 13 (7.2%) Thick - 27 (14.9%)	4.2 ± 2.2 to 7.8 ± 1.8 mm	0.794
	Severe crowding		Thin - 23 (12.7%) Thick - 61 (33.7%)	2.7 ± 1.5 to 7.3 ± 2.02 mm	
Kaya et al.[13]	Class I		0.73 ± 0.17 mm (0.299-1.388)	2.13 ± 1.27 to 3.97 ± 1.43 mm	
	Class II		0.72 ± 0.16 mm (0.333-1.182)	1.94 ± 1.48 to 3.99 ± 1.73 mm	0.140
	Class III		0.66 ± 0.17 mm (0.275-0.961)	1.90 ± 1.08 to 3.58 ± 1.93 mm	
	Mild crowding		0.71 ± 0.16 mm (0.324-1.218)	2.46 ± 1.29 to 3.8 ± 1.24 mm	
	Moderate crowding		0.69 ± 0.21 mm (0.275-1.388)	2.44 ± 1.39 to 3.84 ± 1.45 mm	0.321
	Severe crowding		0.75 ± 0.14 mm (0.448-1.056)	2.15 ± 1.08 to 2.73 ± 1.48 mm	
Matarese et al.[1]	Class I		Thin -19 (57.6%), Thick- 15 (34.9%)	NA	
	Class II		Thin - 7 (21.2%), Thick- 14 (32.6%)	NA	0.143
	Class III		Thin - 7 (21.2%), Thick- 14 (32.6%)	NA	
	Pro-inclination		Medium, followed by thin biotype more prevalent	4.08 ± 0.78 mm at baseline 3.42 ± 0.78 mm at 9 month of treatment	NA
	Retro-inclination		Thick biotype more prevalent	4.50 ± 0.85 mm at baseline 4.97 ± 0.87 mm at 9 month of treatment	NA
Zawawi and Al-Zahrani[15]	Maxillary incisor	Inclination in mm	Thin GT - 25.5 ± 3.4	NA	0.89
			Thick GT - 25.4 ± 3.3	NA	
		Position in mm	Thin GT - 6.3 ± 2.1	NA	0.87
			Thick GT - 6.3 ± 2.2	NA	
		Crowding in mm	Thin GT - 2.07 ± 1.7	NA	0.85
			Thick GT - 2.01 ± 1.8	NA	
	Mandibular incisor	Inclination in mm	Thin GT - 97.05 ± 6.3	NA	0.02
			Thick GT - 94.6 ± 5.9	NA	
		Position in mm	Thin GT - 5.7 ± 2.8	NA	0.02
			Thick GT - 4.7 ± 2.7	NA	
		Crowding in mm	Thin GT - 3.2 ± 2.4	NA	0.52
			Thick GT - 3.5 ± 2.3	NA	
Zawawi et al.[14]	Class I		Thin - 60 (42.9%) Thick - 80 (57.1%)	NA	
	Class II		Thin - 15 (44.1%) Thick - 19 (55.9%)	NA	0.6
	Class III		Thin - 14 (53.8%) Thick - 12 (46.2%)	NA	

NA, Not available; GT, Gingival biotype; WKG, Width of keratinized gingiva

DISCUSSION

Various risk factors are associated with gingival recession, particularly in the mandibular anterior region in orthodontic patients. These risk factors include: age of the patient, periodontal health status, tobacco smoking, duration of orthodontic treatment, amount of force applied, the amount and type of tooth movement, GTs, and WKG.[4,5,6-9] GT is central to maintaining the periodontal health by determining the periodontium behavior to various bacterial, chemical and physical insults. Individuals with a thin GT are more prone to gingival recession following orthodontic treatment.[7,12] This systematic review was conducted to check the relationship between GT and malocclusion. The review included six cross-sectional studies.[1,11-15]

The method of assessment of GT: Different methods are used for assessing the GT like invasive and non-invasive. The noninvasive methods include visual assessment, probe transparency, ultrasonic devices, and cone-beam computed tomography. However, they have limitations like lack of reliability, need of repeatable measurements, and potential side effects of radiation exposure in routine clinical practice.[18-20] Invasive methods include trans-gingival probing, parallel profile radiography technique, and histological section. In this review, three studies[12,14,15] used periodontal probing, three studies[1,11,13] used trans gingival probing. The most frequently used techniques in modern orthodontic practice for GT measurements are periodontal probing and transgingival probing because it is easy to perform, reproducible, reliable, objective centered and less expensive.[7,11,14]

Tooth position, and GTs: GTs change with the position of the teeth during the eruption period. With the increasing age, these changes will reduce because the connective tissue becomes denser, the epithelium becomes thinner, the cell count decreases, and keratinization increases.[6,7] GT varies with tooth position in the arch. In this review, four studies showed medium to thin GT among individuals with pro-inclination of incisors.[7,11,13,15] Gingival thickness varies according to arch type and in the present review Jing et al.[12] showed a significantly higher prevalence of thin GT in mandibular teeth compared to maxillary teeth among subjects with skeletal Class III malocclusion.

GT and malocclusion type: GT changes with facial characteristics, facial profile, and tooth position.[6] In this review, four studies compared GT among subjects with Angle's classification of malocclusion.[1,11,13,14] No relationship was observed between Angle's classification of malocclusion and GT.

Relationship between GT and the WKG: The adequate WKG is an essential component in maintaining periodontal health.[21] Keratinized gingiva provides a firm and stable basis for maintaining good oral hygiene and during restorative and esthetic procedures. Studies have reported contradictory results regarding the WKG that would maintain periodontal health during orthodontic treatment.[11,13,20] In this review, three studies assessed the WKG and the results showed thin GT with a narrow zone of the WKG compared to thick GT.[11-13]

The limitation of the present systematic review is, the meta-analysis cannot be performed due to heterogeneity of data among included study. A future research based on homogeneous data derived from valid randomized control trials would help to substantiate the finding of this review.

CONCLUSION

In conclusion, the present systematic review cannot show a definite association between thin GT among individuals with severe crowding compared to mild crowding. Thin GT presented with a narrow zone of the WKG compared to a thick GT. No relationship was observed between the Angle's classification of malocclusion and GT. Further, future studies with the inclusion of vertical and sagittal skeletal relationship, tooth position, and overjet/overbite are needed to arrive at the conclusive evidence in this field of research.

Ethics

Ethics Committee Approval: Approval from the Institutional Review Board was not required.

Informed Consent: N/A.

Peer-review: Internally peer-reviewed.

Author Contributions: Concept - Y.A.T., R.N.M., S.B., R.S., B.S.M.; Design - Y.A.T., R.N.M., S.B., R.S., B.S.M.; Data Collection and/or Processing - Y.A.T., R.N.M., S.B., R.S., B.S.M.; Analysis and/or Interpretation - Y.A.T., R.N.M., S.B., R.S., B.S.M.; Literature Review - Y.A.T., R.N.M., S.B., R.S., B.S.M.; Writing - Y.A.T., R.N.M., S.B., R.S., B.S.M.

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Erratum

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Tamer İ, Öztaş E, Marşan G. Up-to-Date Approach in the Treatment of Impacted Mandibular Molars: A Literature Review. Turk J Orthod. 2020 May 21;33(3):183-191

Figure 1 and Figure 3 are copied from Figure 1 and Figure 5b, inside Neal D. Kravitz's article titled "Surgical Uprighting of Lower Second Molars," published in the January issue of JCO in 2016.

The mistakes have been made inadvertently by the author. For the subtitles of the two figures, which will be corrected below, corrections have been made by adding reference citations.

*The subtitle of Figure 1 on page 184 of the related article has been changed.

- Incorrect subtitle; Figure 1. Lower third molar follicle positioned on top of the second molar, an early sign of second molar impaction

- Corrected subtitle; Figure 1. Lower third molar follicle positioned on top of the second molar, an early sign of second molar impaction

From Kravitz et al. (2016). Kravitz ND, Yanosky M, Cope JB, Silloway K, Favagehi M. Surgical Uprighting of Lower Second Molars. J Clin Orthod. 2016;50:33-40.

*The subtitle of Figure 3 on page 185 of the related article has been changed.

- Incorrect subtitle; Figure 3. Illustration of surgical uprighting procedure

- Corrected subtitle; Figure 3. Illustration of surgical uprighting procedure

From Kravitz et al. (2016). Kravitz ND, Yanosky M, Cope JB, Silloway K, Favagehi M. Surgical Uprighting of Lower Second Molars. J Clin Orthod. 2016;50:33-40.

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