EISSN 2148-9505

Indexed in PubMed, Web of Science and Scopus

Turkish Orthodontic Society

TURKISH JOURNAL of ORTHODONTICS

ORIGINAL ARTICLES

SYSTEMATIC REVIEW

Volume 35
Issue 04
December 2022

AVES

turkjorthod.org

TURKISH JOURNAL of
ORTHODONTICS

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TURKISH JOURNAL of ORTHODONTICS

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Turkish Journal of Orthodontics (Turk J Orthod) is an international, scientific, open access periodical published in accordance with independent, unbiased, and double-blinded peer-review principles. The journal is the official publication of Turkish Orthodontic Society and it is published quarterly on 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.

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Editor in Chief: Derya Germeç Çakan
Address: Bağdat Cad. No: 238, Göztepe,34728 İstanbul/Turkey
Phone: +90 216 468 08 00
Fax: +90 216 468 08 00
E-mail: info@turkjorthod.org

Publisher: AVES
Address: Büyükdere Cad. 105/9 34394 Mecidiyeköy, Şişli, İstanbul, Turkey
Phone: +90 212 217 17 00
Fax: +90 212 217 22 92
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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

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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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Book Section: Suh KN, Keystone JS. Malaria and babesiosis. Gorbach SL, Barlett JG, Blacklow NR, editors. Infectious Diseases. Philadelphia: Lippincott Williams; 2004.p.2290-308.

Books with a Single Author: Sweetman SC. Martindale the Complete Drug Reference. 34th ed. London: Pharmaceutical Press; 2005.

Editor(s) as Author: Huizing EH, de Groot JAM, editors. Functional reconstructive nasal surgery. Stuttgart-New York: Thieme; 2003.

Conference Proceedings: Bengisson S. Sothemin BG. Enforcement of data protection, privacy and security in medical informatics. In: Lun KC, Degoulet P, Piemme TE, Rienhoff O, editors. MEDINFO 92. Proceedings of the 7th World Congress on Medical Informatics; 1992 Sept 6-10; Geneva, Switzerland. Amsterdam: North-Holland; 1992. pp.1561-5.

Scientific or Technical Report: Cusick M, Chew EY, Hoogwerf B, Agrón E, Wu L, Lindley A, et al. Early Treatment Diabetic Retinopathy Study Research Group. Risk factors for renal replacement therapy in the Early Treatment Diabetic Retinopathy Study (ETDRS), Early Treatment Diabetic Retinopathy Study Kidney Int: 2004. Report No: 26.

Thesis: Yılmaz B. Ankara Üniversitesindeki Öğrencilerin Beslenme Durumları, Fiziksel Aktiviteleri ve Beden Kitle İndeksleri Kan Lipidleri Arasındaki Ilişkiler. H.Ü. Sağlık Bilimleri Enstitüsü, Doktora Tezi. 2007.

Manuscripts Accepted for Publication, Not Published Yet: Slots J. The microflora of black stain on human primary teeth. Scand J Dent Res. 1974.

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Manuscripts Published in Electronic Format: Morse SS. Factors in the emergence of infectious diseases. Emerg Infect Dis (serial online) 1995 Jan-Mar (cited 1996 June 5): 1(1): (24 screens). Available from: URL: http:/ www.cdc.gov/ncidodlEID/cid.htm.

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Address: Bağdat Cad. No: 238, Göztepe,34728 İstanbul/Turkey
Phone: +90 216 468 08 00
Fax: +90 216 468 08 00
E-mail: info@turkjorthod.org

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Address: Büyükdere Cad. 105/9 34394 Mecidiyeköy, Şişli, İstanbul, Turkey
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TURKISH JOURNAL of
ORTHODONTICS

Contents

Original Articles

Systematic Review

TURKISH JOURNAL of ORTHODONTICS

DOI: 10.5152/TurkJOrthod.2022.21001

Original Article

Changes in Orbicularis Oris Superior and Masseter Muscle Activities After Upper Incisor Protrusion in Class II Division 2 Malocclusion: An Electromyographic Study

Irmak Ocak[1], Abdullah Ruhi Soylu[2], Müge Aksu[3]

[1]Department of Orthodontics, Ankara Medipol University, Faculty of Dentistry, Ankara, Turkey
[2]Department of Biophysics, Hacettepe University, School of Medicine, Ankara, Turkey
[3]Department of Orthodontics, Hacettepe University, Faculty of Dentistry, Ankara, Turkey

Cite this article as: Ocak I, Ruhi Soylu A, Aksu M. Changes in orbicularis oris superior and masseter muscle activities after upper incisor protrusion in Class II Division 2 malocclusion: An electromyographic study. *Turk J Orthod.* 2022;35(4):231-238.

Main Points

- The incisor protrusion did not affect the electromyography activities of the orbicularis oris superior and masseter muscles at rest position.
- Differences in maximum contraction electromyography measurements of orbicularis oris superior and masseter muscles were observed after 6 months.
- Changes in functional structures should also be taken into account in terms of stability.

ABSTRACT

Objective: This prospective study aimed to evaluate the orbicularis oris superior and masseter muscle activity changes after upper incisor protrusion in CII/2 malocclusion.

Methods: A total of 20 patients (mean age 10.29 ± 0.90 years) with CII/2 malocclusion were selected for the study group. A total of 15 patients (mean age 10.56 ± 1.06 years) with Angle Class I malocclusion were recruited as control. Upper incisors were protruded with utility arch in the study group. Muscle activities were evaluated with Biopac MP150 surface electromyography device before and after upper incisor proclination and at the 6-month retention. Orbicularis oris superior and left–right masseter muscles were recorded during rest electromyography and maximum contraction electromyography. Repeated measures and two-way repeated-measures analysis of variance with Bonferroni correction were used for statistical analysis.

Results: A significant change occurred over time in orbicularis oris superior ($P < 0.001$), left masseter ($P < 0.01$) and right masseter ($P < 0.05$) maximum contraction electromyography in the CII/2 group. However, a significant difference was not found between groups $P > 0.05$. In the CII/2 group, orbicularis oris superior maximum contraction electromyography value was increased after upper incisor protrusion and this increase remained stable. Left masseter and right masseter maximum contraction electromyography measurements were decreased after protrusion and then increased after retention significantly. Rest electromyography values for all muscles were not statistically significant. No significant differences with the control group were found.

Conclusion: Upper incisor protrusion increased orbicularis oris superior activity and the increase remained stable after retention. Masseter activities decreased after protrusion and then increased to the initial values. These changes did not show significant differences with the control group.

Keywords: Angle Class II Division 2 malocclusion, EMG activity, orbicularis oris muscle, masseter muscle

INTRODUCTION

Angle Class II Division 2 (CII/2) malocclusion is characterized by decreased overjet and increased overbite with severe retroclination of the upper incisors. Genetics is given importance in etiology, but environmental factors related to lips, cheeks, and tongue are also held responsible. While some studies hold the high lower lip line

Corresponding author: Müge Aksu, e-mail: muge.aksu@hacettepe.edu.tr

Received: December 30, 2021
Accepted: May 15, 2022
Publication Date: December 30, 2022

responsible for the backward position of the upper incisors,[1,2] some studies point to strong masseter muscles and increased masticatory forces.[3,4]

Electromyography (EMG) involves monitoring and interpretation of electrical activities generated by muscle contraction. While evaluating the activities of the muscles, it is possible to record during rest and functions such as chewing, swallowing, and clenching. The aim of orthodontic treatment is not only to provide ideal occlusion but also to ensure balance and stability of the entire stomatognathic system. Therefore, electromyographic evaluations have become more important in diagnosing and monitoring orthodontic treatments, as it is a noninvasive, objective, and precise method.[5]

In recent studies, the orbicularis oris muscle activity of individuals with CII/2 malocclusion has been investigated and various results have been reported.[2,6] Lapatki et al.[2] found no statistically significant difference between the groups in which they evaluated the orbicularis oris inferior, orbicularis oris superior (OOS), depressor labii inferior, and mentalis muscle activities of patients with CII/2 and Angle Class I malocclusion. Lowe and Takada,[6] on the other hand, reported that the orbicularis oris muscle amplitudes at rest and during maximum intercuspation of CII/2 malocclusion were higher compared to Angle Class I and Angle Class II division 1 (CII/1) malocclusions. It was also stated that the amplitude was related to the retroclined upper central incisors and the occlusal plane.

It has been shown that the form and functions of the masticatory muscles are closely related to the morphological features of the muscles and related skeletal structures.[7,8] On the contrary, it is necessary to consider that the changes that will occur in the hard tissues during orthodontic treatment will also cause a response in the muscles. In this respect, the compatibility of functional structures of patients with CII/2 malocclusion to hard tissue changes occurring in the early development stage is unknown. Therefore, the first aim of this study was to investigate the muscle activities of Angle Class I and Angle CII/2 malocclusions. The secondary aim was to evaluate whether increasing the inclination of the upper incisors in CII/2 malocclusion causes any changes in the OOS and masseter muscle activities. The null hypothesis was that increasing the inclination of the upper incisors would not change the muscle activities.

METHODS

A prospective study was conducted in accordance with the Declaration of Helsinki guidelines and was approved by the Ethics Committee of Hacettepe University (Approval number KA-15027). A total of 35 patients and their parents were informed about the purpose of this study, and they were asked to sign an informed consent form.

The study group consisted of 20 subjects (mean age: 10.29 ± 0.90 years) with CII/2 malocclusion. The inclusion criteria in the study group were: (1) horizontal growth pattern, (2) overbite greater than 4 mm, (3) retroclined upper incisors, (4) cusp-to-cusp and/or Class 2 molar relationship, (5) no congenitally missing upper incisors, and (6) no history of orthodontic treatment.

The control group, on the other hand, consisted of 15 Angle Class I malocclusion subjects (mean age: 10.56 ± 1.06 years) with minimal crowding. Inclusion criteria for the control group were (1) normally inclined upper incisors, (2) no soft tissue incompetence, (3) no congenitally missing upper incisors, (4) orthognathic profile with normal facial growth pattern, and (5) no plan for any fixed or removable orthodontic appliance therapy.

Exclusion criteria for both groups were (1) having any systemic diseases or craniofacial deformities, (2) having any bad habits associated with perioral muscles, and (3) having any temporomandibular disorders.

Initial Records

The aim of the study was to investigate whether changes in upper incisor position would have any effect on OOS, left masseter (LM), and right masseter (RM) muscles at rest and during 2 oral activities (tightening the lips and clenching teeth), and therefore, electromyographic evaluation was preferred.

Electromyographic activities were recorded before appliance insertion (T0), at the end of the incisor protrusion (T1), and at the end of 6-month retention (T2). During the study, no treatment was applied to the control group and dentition follow-up appointments were scheduled. Therefore, in coordination with the study group, control group recordings were taken at similar intervals between recordings.

Digital lateral cephalometric radiographs of CII/2 patients were taken at T0, T1, and T2 stages, with the teeth in centric occlusion and the lips without tension in natural head position.

Orthodontic Treatment Protocol

After T0 recordings were obtained from the study group, a passive transpalatal arch was applied to the maxillary first molars. The purpose of the transpalatal arch application was to increase the anchorage of the upper molar teeth. At the same appointment, conventional brackets (0.018-inch slots, Gemini, 3M Unitek, Monrovia, CA, USA) were bonded to the upper incisors. According to the amount of crowding, 0.016-inch or 0.016 × 0.016-inch nickel-titanium leveling utility arch was applied. After leveling was completed, the protrusion utility arch from 0.016 × 0.022-inch blue Elgiloy wire was applied. Subjects were observed every 4 weeks. The inclination of the upper incisors was evaluated only clinically to determine whether adequate protrusion was achieved and to avoid unnecessary radiation exposure. When overjet was approximately doubled and sufficient protrusion was obtained, all appliances were removed and records were taken at T1. Hawley retainer was applied as a 6-month retention period until T2.

Radiographic Evaluation

Cephalometric measurements were analyzed using Dolphin Imaging software version 11.8 (Dolphin Imaging & Management Solutions, Chatsworth, Calif, USA). Lateral cephalometric analysis

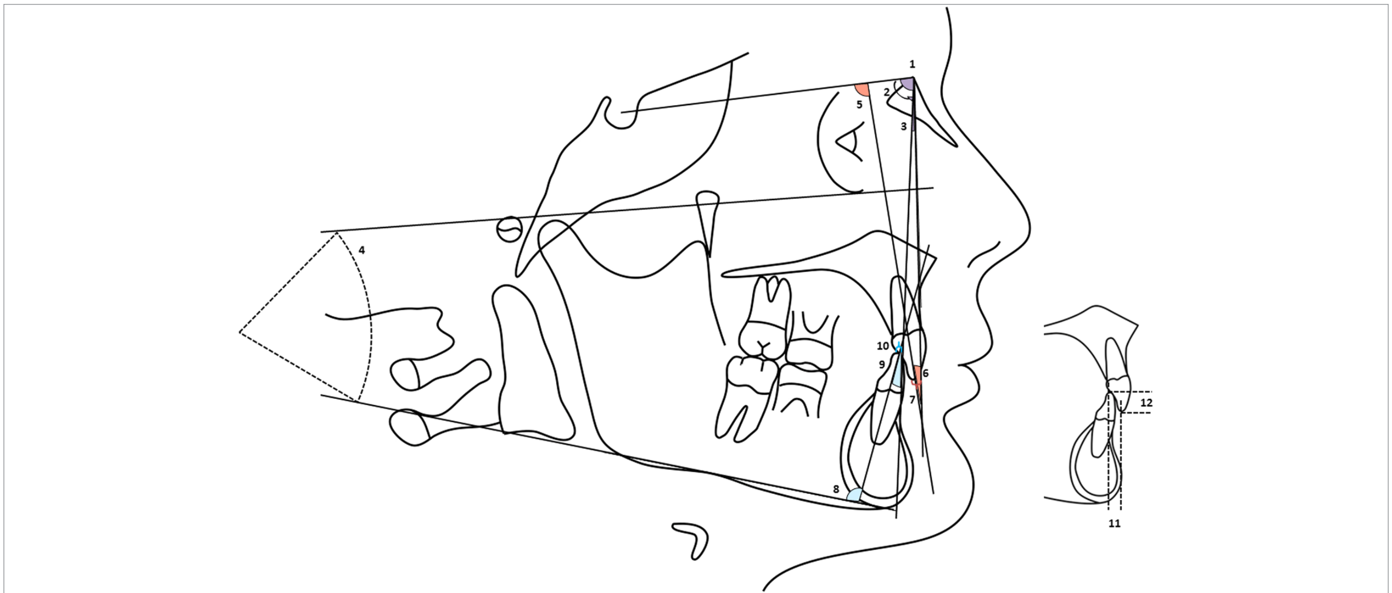

Figure 1. Cephalometric measurements. (1) SNA angle, (2) SNB angle, (3) ANB angle, (4) FMA angle, (5) U1-SN angle, (6) U1-NA angle, (7) U1-NA distance, (8) IMPA, (9) L1-NB angle, (10) L1-NB distance, (11) overjet, and (12) overbite

were performed to define skeletal and dentoalveolar features in the study group. Cephalometric measurements are shown in Figure 1.

Electromyographic Evaluation

Biopac MP150 device with EMG amplifier (Biopac Systems Inc., Calif, USA) was used to record muscle activities in T0, T1, and T2 stages. Ag/AgCl solid and self-adhesive bipolar electrodes (plusMED, Bio Protech Inc., Gangwon-do, Korea) were used to record surface electromyography (sEMG) activities. Electromyography amplifier gain, passband, common-mode rejection rate, and sampling frequency were 1000×, 1-500 Hz, 80 dB, and 1000 Hz, respectively.

Subjects were asked to sit comfortably upright in a chair with their hands in their laps, without head support. Recordings were taken in an anechoic room to prevent individuals from being affected by external stimuli. However, the door of the anechoic room was not closed to avoid anxiety.

Electromyographic recordings were taken from OOS, LM, and RM muscles. Before placing the electrodes, the skin was cleansed with alcohol and dried to reduce skin impedance.

Because the OOS muscle was small in size, the adhesive area around the electrodes was removed. The distance between the 2 electrodes was adjusted to be 1 cm, and they were attached 4 mm above the vermilion border with the help of plasters according to the technique described by Lapatki et al.[9] at an equal distance to both sides of the philtrum. The placement of the electrodes of the OOS muscle is shown in Figure 2. Masseter muscle electrodes were placed parallel to the muscle fibers, and the distance between the 2 electrodes was set to be 2 cm. The upper masseter electrode was aligned according to the technique described by Ferrario and Sforza,[10] coinciding with the intersection of the tragus-labial commissure and exocantion-gonion lines. A ground electrode was secured over the mastoid. The placement of the masseter muscle and ground electrodes is shown in Figure 3.

Electromyographic recordings were taken at the following positions:

1. *Physiological rest position*: Subjects were asked to look forward after sitting and waiting without moving their jaws

Figure 2. The orbicularis oris muscle electrodes

Figure 3. The masseter muscle electrodes

and/or teeth. After stabilizing the position, recordings were taken for 6 seconds for each muscle group.

2. *Tightening of the lips*: For EMG recording of the OOS muscle, a tongue depressor was placed between the lips of the individuals in such a way that it would not contact their teeth, and the subjects were asked to tighten their lips as much as possible. The recording process continued for 10 s.
3. *Clenching*: For EMG recording of masseter muscles, 2 cotton rolls were placed between the posterior teeth of the subjects on both sides, and they were asked to clench their teeth as much as possible. The recording process continued for 10 seconds.

Separate recordings were taken for each muscle group so that the electrodes did not interfere with the movement of the muscle. Lip tightening and teeth clenching recordings were repeated three times, and a 3-min rest period was given for the muscles between each recording. During the recordings, the sound with the command "increase" was repeated so that the recording would not be interrupted.

MATLAB (MathWorks, Mass, USA) was used to evaluate the EMG data. Signals were filtered with a 20-Hz high pass filter (6th order, Butterworth) to remove motion artifacts. A root-mean-square (RMS) filter (time window: 200 ms) was then applied to the signals. The lowest EMG amplitude within 2 seconds before the onset of maximum voluntary contraction (MVC) was defined by the software and recorded as a resting EMG (r-EMG). The highest RMS value within 6 seconds from the onset of MVC was automatically identified by the software and recorded as maximum contraction (m-EMG). The reason why the recording after the first 6 seconds is not used in the evaluation is to prevent the disruptive effect of muscle fatigue. A single value was obtained by taking the arithmetic mean of the left and right OOS muscle measurements, and the LM and RM muscles were evaluated separately.

Statistical Analysis

Statistical Package of Social Sciences Statistics software (version 21; IBM Corp, Armonk, NY, USA) was used for data analysis. The normal distribution of data was confirmed by the Kolmogorov–Smirnov test. In repeated measurements, intra-observer reliability was evaluated with the intra-class correlation coefficient. All cephalometric measurements were performed by the first author (I.O.), and measurements of 5 patients were repeated within 15 days. Previously repeated measurements were used to assess the reliability of muscle activities. Descriptive statistics were expressed as mean ± standard deviation for continuous variables. Two groups were evaluated using the independent sample t-test for quantitative variables and the chi square test for categorical variables. Repeated-measures analysis of variance (ANOVA) was used to observe the differences of the variables in the groups according to the time periods. Two-way repeated-measures ANOVA was used to examine the main effects and interaction effects between malocclusion groups at all stages for EMG measurements. As post hoc multiple comparisons, Bonferroni correction was applied. A power calculation indicated that the achieved power for the study was 0.97. The results for $P < .05$ were accepted to be significant statistically.

RESULTS

Data are normally distributed according to the Kolmogorov–Smirnov normality test. The intra-class correlation coefficient for cephalometric measurements is between 0.972 and 1.000, and for electromyographic measurements, it is in the range of 0.957-0.986. There was no statistically significant difference between the groups in terms of age and gender distribution ($P > .05$, Table 1).

Skeletal and dentoalveolar cephalometric measurements of the study group are presented in Table 2. Maxillomandibular discrepancy was slightly decreased (0.86°) according to the ANB angle ($P < .001$, Table 3). As shown in Table 3, measurements showing both the upper incisor position (U1-SN angle, U1-NA angle, U1-NA distance) and the lower incisor position (IMPA, L1-NB angle, L1-NB distance) are significant after protrusion increased significantly ($P < .001$, T1-T0) and did not change during retention

Table 1. Age and gender distributions of the groups

	Study Group	Control Group	*P*
Female	8	5	.960
Male	12	10	
Total	20	15	
Age (years) *	10.29 ± 0.90	10.56 ± 1.06	.418

* Data expressed as mean ± standard deviation.

Table 2. Repeated measures ANOVA results for the skeletal and dentoalveolar lateral cephalometric measurements of study group

	T0	T1	T2	
	Mean ± SD	Mean ± SD	Mean ± SD	*P*
SNA (°)	80.73 ± 2.98	80.20 ± 3.27	80.30 ± 3.42	.099
SNB (°)	74.79 ± 3.02	74.82 ± 3.34	75.25 ± 3.45	.192
ANB (°)	5.92 ±1.37	5.29 ± 1.64	5.06 ± 1.68	.000***
FMA (°)	20.80 ± 2.49	20.97 ± 2.72	21.19 ± 2.73	.117
U1-SN (°)	89.49 ± 5.69	108.91 ± 5.25	106.71 ± 6.00	.000***
U1-NA (°)	8.69 ± 5.37	28.70 ± 4.67	26.41 ± 3.99	.000***
U1-NA (mm)	-1.39 ± 1.62	4.90 ± 1.51	4.65 ± 1.24	.000***
IMPA (°)	95.50 ± 6.58	99.28 ± 5.36	97.75 ± 5.12	.000***
L1-NB (°)	19.27 ± 7.19	24.14 ± 5.69	22.88 ± 6.00	.000***
L1-NB (mm)	2.20 ± 2.31	3.25 ± 2.12	3.36 ± 2.29	.000***
Overjet (mm)	4.43 ± 1.11	8.75 ± 1.70	8.04 ± 1.73	.000***
Overbite (mm)	5.85 ± 1.15	5.08 ± 0.85	3.66 ± 1.40	.000***

SD, standard deviation. ****P* < .001.

(*P* > .05, T2-T1). There was a statistically significant increase (*P* < .001, T1-T0) in the post-protrusion overjet (4.32 mm) and a slight but significant decrease after the retention period (*P* < .05, T2-T1, Table 3). Overbite decreased significantly by 0.78 mm after protrusion (*P* < .05, T1-T0) and continued to decrease significantly after the retention period (*P* < .001, T2-T1, Table 3).

A statistically significant change was observed in OOS m-EMG (*P* < .001), LM m-EMG (*P* < .01), and RM m-EMG (*P* < .05) measurements with treatment (Table 4). Interaction between malocclusion and treatment was observed only in RM m-EMG (*P* < .05, Table 4).

Table 4. Two-way ANOVA results for the electromyographic measurements

	P		
	Malocclusion	Treatment	Malocclusion-Treatment
OOS r-EMG (µV)	0.135	0.643	0.595
OOS m-EMG (µV)	0.213	0.000***	0.462
LM r-EMG (µV)	0.282	0.400	0.744
LM m-EMG (µV)	0.054	0.003**	0.279
RM r-EMG (µV)	0.735	0.499	0.506
RM m-EMG (µV)	0.093	0.010*	0.034*

EMG, electromyography; OOS, orbicularis oris superior; LM, left masseter muscle; RM, right masseter muacle; r-EMG, rest EMG; m-EMG, maximum contraction EMG.
**P* < .05, ***P* < .01, ****P* < .001.

Comparison of electromyographic measurements between study and control groups is shown in Table 5. At the beginning of the treatment, a difference was observed between the study and control groups in RM m-EMG (*P* < .05, T0, Table 5). There was no difference between the groups after protrusion (*P* > .05, T1, Table 5), but there was a significant difference in LM m-EMG at the end of retention (*P* < .05, T2, Table 5).

Orbicularis oris superior maximum contraction electromyography increased significantly after protrusion (*P* < .001, T1-T0, Table 6) in the study group, and this increase remained constant (*P* < .05, T2-T0, Table 6). Left masseter and right masseter maximum contraction electromyography decreased significantly after protrusion (*P* < .01, T1-T0, Table 6) and increased significantly after retention (*P* < .05, T2-T1, Table 6). Changes in r-EMG measurements for all muscles were not statistically significant at all treatment stages (*P* > .05, Table 6).

Table 3. Lateral cephalometric changes of the study group in different treatment stages by Bonferroni Test

	T1-T0		T2-T1		T2-T0	
	Mean Difference ± SD	*P*	Mean Difference ± SD	*P*	Mean Difference ± SD	*P*
SNA (°)	-0.53 ± 0.26	0.169	0.10 ± 0.19	0.187	-0.43 ± 0.30	0.503
SNB (°)	0.03 ± 0.29	1.000	0.43 ± 0.20	0.145	0.46 ± 0.32	0.514
ANB (°)	-0.53 ± 0.21	0.055	-0.33 ± 0.20	0.333	-0.86 ± 0.20	0.001**
FMA (°)	0.17 ± 0.22	1.000	0.26 ± 0.94	0.080	0.40 ± 0.22	0.246
U1-SN (°)	19.43 ± 1.47	0.000***	-2.21 ± 0.97	0.107	17.22 ± 1.43	0.000***
U1-NA (°)	20.02 ± 1.45	0.000***	-2.30 ± 0.90	0.058	17.72 ± 1.31	0.000***
U1-NA (mm)	6.29 ± 0.43	0.000***	-0.26 ± 0.28	1.000	6.03 ± 0.30	0.000***
IMPA (°)	3.78 ± 0.76	0.000***	-1.53 ± 0.66	0.096	2.25 ± 0.74	0.020*
L1-NB (°)	4.88 ± 0.69	0.000***	-1.27 ± 0.63	0.172	3.61 ± 0.75	0.000***
L1-NB (mm)	1.06 ± 0.21	0.000***	0.11 ± 0.15	1.000	1.17 ± 0.20	0.000***
Overjet (mm)	4.32 ± 0.36	0.000***	-0.71 ± 0.23	0.019*	3.62 ± 0.36	0.000***
Overbite (mm)	-0.78 ± 0.24	0.014*	-1.42 ± 0.28	0.000***	-2.19 ± 0.25	0.000***

SD, standard deviation.
**P* < .05, ***P* < .01, ****P* <.001.

Table 5. Comparison of electromyographic measurements according to the treatment stages between the study and control group by Bonferroni Test

	T0			T1			T2		
	Study Group	Control Group	*P*	Study Group	Control Group	*P*	Study Group	Control Group	*P*
OOS r-EMG (µV)	1.42 ± 0.31	1.62 ± 0.52	.162	1.43 ± 0.34	1.70 ± 0.59	.090	1.43 ± 0.40	1.56 ± 0.58	.437
OOS m-EMG (µV)	169.70 ± 53.63	162.36 ± 41.59	.663	205.45 ± 54.54	179.96 ± 33.02	.119	203.73 ± 49.88	184.36 ± 40.85	.229
LM r-EMG (µV)	1.27 ± 0.34	1.12 ± 0.43	.258	1.16 ± 0.34	1.12 ± 0.25	.688	1.14 ± 0.36	1.06 ± 0.27	.477
LM m-EMG (µV)	348.54 ± 208.39	259.09 ± 101.20	.136	247.58 ± 113.14	205.73 ± 74.71	.223	334.21 ± 166.97	221.81 ± 100.92	.028*
RM r-EMG (µV)	1.21 ± 0.49	1.15 ± 0.37	.663	1.06 ± 0.27	1.17 ± 0.27	.217	1.07 ± 0.37	1.11 ± 0.31	.769
RM m-EMG (µV)	356.25 ± 225.13	225.39 ± 106.08	.045*	227.41 ± 107.55	219.33 ± 104.33	.825	318.07 ± 135.59	243.07 ± 119.45	.098

EMG, electromyography; OOS, orbicularis oris superior; LM, left masseter muscle; RM, right masseter muacle; r-EMG, rest EMG; m-EMG, maximum contraction EMG. Data expressed as mean ± standard deviation. *$P < .05$.

Table 6. EMG changes in different treatment stages between study and control group by Bonferroni Test

		T1-T0		T2-T1		T2-T0	
	Group	Mean Difference ± SD	*P*	Mean Difference ± SD	*P*	Mean Difference ± SD	*P*
OOS r-EMG (µV)	Study group	0.01 ± 0.10	1.000	0.01 ± 0.09	1.000	0.02 ± 0.10	1.000
	Control group	0.09 ± 0.11	1.000	-0.14 ± 0.10	0.556	-0.05 ± 0.10	1.000
OOS m-EMG (µV)	Study group	35.75 ± 8.29	.000***	-1.73 ± 10.97	1.000	34.03 ± 9.57	.003**
	Control group	17.60 ± 9.57	.225	4.40 ± 12.66	1.000	22.00 ± 11.05	.164
LM r-EMG (µV)	Study group	-0.11 ± 0.10	.838	-0.02 ± 0.08	1.000	-0.13 ± 0.10	.546
	Control group	0.00 ± 0.11	1.000	-0.06 ± 0.10	1.000	-0.06 ± 0.11	1.000
LM m-EMG (µV)	Study group	-100.96 ± 29.72	.005**	86.63 ± 23.24	.002**	-14.33 ± 33.72	1.000
	Control group	-53.37 ± 34.32	.388	16.09 ± 26.84	1.000	-37.28 ± 38.94	1.000
RM r-EMG (µV)	Study group	-0.16 ± 0.12	.618	0.02 ± 0.08	1.000	-0.14 ± 0.10	.546
	Control group	0.03 ± 0.14	1.000	-0.07 ± 0.09	1.000	-0.04 ± 0.12	1.000
RM m-EMG (µV)	Study group	-128.84 ± 32.20	.001**	90.66 ± 21.64	.001**	-38.18 ± 34.85	.844
	Control group	-6.06 ± 37.18	1.000	23.74 ± 24.99	1.000	17.68 ± 40.24	1.000

EMG, electromyography; SD, standard deviation; OOS, orbicularis oris superior; LM, left masseter muscle; RM, right masseter muacle; r-EMG, rest EMG; m-EMG, maximum contraction EMG. **$P < .01$, ***$P < .001$.

DISCUSSION

The goal of orthodontic treatment is not only to align the teeth but also to provide a balanced chewing pattern with balanced muscle activities. Therefore, determining the etiology and post-treatment changes originating from soft tissues is very important for the success of orthodontic treatment.

CII/2 malocclusion is characterized by dental features such as retroclined upper incisors and deep bite. However, in addition to dental features, skeletal pattern, facial profile, and muscular properties are also very characteristic. It has been stated that genetics is not the only factor affecting CII/2 malocclusion,[11] that the high lip line is associated with retroclination of the upper incisors.[1,2,12] Lapatki et al.[13] confirmed that the risk of relapse is high unless etiologic factors are eliminated during treatment. Therefore, possible etiological factors associated with the perioral muscles should be identified and monitored for the stability of orthodontic treatment. This study was conducted to evaluate the changes in the OOS and masseter muscles with upper incisor protrusion in CII/2 malocclusion.

In the present study, spontaneous protrusion of the lower incisors occurred with the protrusion of the upper incisors. Overjet increased significantly while overbite decreased. Timmons[14] reported that protrusion of the upper incisors and reduction of the overbite with orthodontic treatment resulted in the spontaneous forward repositioning of the mandible. Unlocking the mandible following proclination of the upper incisors in growing patients allowed the mandible to grow horizontally.[15] Similarly in our study, insignificant changes were observed in SNA and SNB angles, and ANB angle was significantly decreased by about 1˚. This significance was associated with spontaneous growth of the mandible.

In addition to technical factors, age, gender, skeletal morphology, bad oral habits, skin/soft tissue thickness, and psychological factors affect EMG results. Experimental stress causes an increase in masticatory muscle EMG activities.[16] Therefore, it is important for the patient to be in a quiet place away from distractions to avoid anxiety and stress. Additionally, as a different method, Ingervall and Thüer[17] suggested excluding the first records from the study to minimize the effects of anxiety. In our study, patients were seated in an anechoic room so that they could not see the computer screen, and all electronic devices were turned off to minimize external factors.

The literature on the relationship between malocclusion types and electromyographic activities of facial and masticatory muscles is inconclusive. Antonini et al.[18] reported that there were significant differences between CII/2 and Angle Class III malocclusions in the activities of the masticatory muscles during chewing and swallowing but not at rest. In a study by Lowe and Takada,[6] orbicularis oris muscle activities increased in CII/2 malocclusion during the rest and maximum intercuspation when compared with Angle Class I and CII/1 malocclusion. In another study, no significant difference was found between Angle Class I and CII/2 malocclusion in terms of orbicularis oris muscle activities.[2] According to our results, it was determined that malocclusions did not affect the activities of both OOS and masseter muscles. Contrary to our findings, Petrovic et al.[19] showed that masseter muscle activity was lower in CII/2 malocclusion compared to Angle Class I occlusion for both rest and MCV measurements.

Electromyography is also used to evaluate the efficacy of treatment and orthodontic appliances. However, there are few studies examining muscle activity changes with orthodontic treatment in CII/2 malocclusion. In a study examining the bioelectrical activity of masticatory muscles during activator therapy in CII/2 malocclusion, it was reported that muscle activities increased in the first year of treatment and decreased after a year of treatment.[19] Thüer et al.[20] reported that no significant change in masticatory muscle activities was seen at the end of activator therapy, while there were significant changes during treatment periods. Unlike our study, there was an increase in OOS and a decrease in the masseter muscle, which is a significant change in the maximum contraction of all muscles after treatment.

It is known that the postural activity of the orbicularis oris muscle is an important factor in incisor position. Few studies have shown that orbicularis oris muscle activity affects the inclination of the upper incisors.[5,21-23] However, Lowe[24] stated that the activity of the superior orbicularis oris muscle did not appear to be associated with the inclination of the upper incisors, and Ahlgren et al.[25] found a negative correlation between them. From a different perspective, we evaluated the effect of the upper incisor position on muscle activities and determined that the protrusion of the upper incisors and the responses of the OOS and masseter muscles were different. While OOS r-EMG measurements were not significant, the OOS m-EMG value increased due to the protrusion of the upper incisors, and this increase remained stable at the end of the 6-month retention period. Also, while the resting measurements were not significant, the LM m-EMG and RM m-EMG measurements decreased statistically significantly after protrusion and increased significantly after the retention period.

The first step in the treatment of CII/2 malocclusion is to correct the position of the upper incisors and convert the patient to a CII/1 malocclusion. The same protocol was followed in this study, and the position of the lips changed after protrusion as expected. Due to the new position of both teeth and lips, the performance of oral functions also changes. Soft tissues exert more effort to perform the same functions. Tosello et al.[26] reported that OOS muscle activity was higher during tightening of their lips in individuals with CII/1 malocclusion and incompetent lips. As in our study, increased OOS muscle activity is thought to compensate for other perioral muscle movements to maintain proper function. This raises another point regarding the retention of CII/2 malocclusion, as this malocclusion has always been thought to be prone to relapse.[27] Our results indicate that increased OOS muscle activity on upper incisors that do not return to the initial value supports the idea of the possibility of relapse.

Removable acrylic plate treatment was applied by Thüer et al.[20] to evaluate changes in masticatory muscle activities. The authors found that the activity of the anterior and posterior temporal muscles was decreased during protrusion and intrusion of the upper incisors, whereas the activity of the masseter muscles was not significant. In the current study, LM and RM muscles were evaluated and discussed together. The reason for this is the masseter muscles can be clinically affected by many individual factors such as chewing patterns, eating habits, and pain caused by tooth eruption and therefore, subjects generally showed a predominance to the one side. In accordance with our study, Ferrario et al.[28] showed a predominance on the right side. The masseter muscle activities decreased statistically significantly after protrusion, while they increased significantly after the retention period. We assume that these results in our study are related not only to upper incisor protrusion but also to fixed treatment mechanics and changes in occlusion. Two studies evaluating anterior temporalis and masseter muscle activities with flexible fixed functional appliances reported that muscle activities decreased significantly after the first month of functional appliance therapy and returned to pre-appliance levels toward the end of 6 months after treatment.[29,30] Miyamoto et al.[31] stated that the masseter muscle activity decreased after fixed orthodontic treatment and this decrease returned to normal after 6 months. In accordance with the literature, our findings were thought to result from pain and discomfort during orthodontic treatment and neuromuscular adaptations after appliance removal.

This is the first study to investigate muscle changes after upper incisor protrusion via fixed appliances. Limitations of this study may be the small number of patients in the groups and the fact that tooth transitions may affect the clenching pattern, muscle activity, and discomfort. However, understanding the effects of early treatment in CII/2 malocclusion is important both to prevent the severity of the malocclusion and to obtain long-term stable treatment results. In further studies, our study design can be used to examine muscle changes that occur at different malocclusions. Our results show that OOS and masseter muscle activities are affected by the protrusion of the upper incisors. There will be a risk of relapse without a clear understanding of the etiological factors of CII/2 malocclusion. As a result, orthodontists should consider changes in jaw muscle activities during orthodontic treatment.

CONCLUSION

- Malocclusions did not affect the activities of both OOS and masseter muscles.
- The activity of OOS muscle increased after maxillary incisor protrusion, and this increase remained stable after the retention period.
- The activities of LM and RM activities decreased after protrusion and increased back to initial values after the retention period.
- Further long-term follow-up studies are required to evaluate muscle activity changes due to growth and orthodontic treatment.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Hacettepe University (Approval No: KA-15027).

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

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – I.O., M.A.; Design – I.O., M.A.; Supervision – A.R.S., M.A.; Materials – I.O.; Data Collection and/or Processing – I.O., A.R.S.; Analysis and/or Interpretation – I.O., A.R.S., M.A.; Literature Review – I.O., M.A.; Writing – I.O., M.A.; Critical Review – A.R.S., M.A.

Acknowledgments: The authors would like to thank Jale Karakaya for her assistance with the statistical analysis.

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

Funding: This study was supported by Hacettepe University Scientific Research Coordination Unit (Project Number: TDH-2017-10747).

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TURKISH JOURNAL of ORTHODONTICS

DOI: 10.5152/TurkJOrthod.2022.21237

Original Article

Cephalometric Variability Among Siblings: A Pilot Study

Katharine L. Marcks, Yihong Zhao, Melih Motro, Leslie A. Will

Department of Orthodontics and Dentofacial Orthopedics, Boston University Henry M. Goldman School of Dental Medicine, Boston, MA, USA

Cite this article as: Marcks KL, Zhao Y, Motro M, Will LA. Cephalometric variability among siblings: A pilot study. *Turk J Orthod.* 2022;35(4):239-247.

Main Points

- Families with at least 4 postpubertal siblings were examined cephalometrically to see if a clinically meaningful family resemblance could be identified.
- Cephalometric measurements that could indicate the need for different treatment plans were included.
- The majority of families demonstrated similarities in their cephalometric measurements.
- These measurements, however, while not statistically different had a large enough range that orthodontic treatment planning might differ for the siblings.
- Cephalometric measurements from one sibling cannot reliably be used to predict the cephalometric measurements of another sibling.

ABSTRACT

Objective: To determine whether multiple siblings resemble one another in their craniofacial characteristics as measured on cephalometric radiographs.

Methods: This study was conducted retrospectively using the Forsyth Moorrees twin sample. A total of 32 families were included, each with ≥4 postpubertal siblings, totaling 142 subjects. Only 1 monozygotic twin was included per family. Headfilms were digitized, skeletal landmarks were located, and 6 parameters that indicated sagittal jaw relationships and vertical status were measured. Diverse statistical approaches were used. Dixon's Q-test detected outliers in a family for a given parameter. Manhattan Distance quantified similarity among siblings per parameter. Scatter plots visually displayed subject's measure relative to the mean and standard deviation of each parameter to assess the clinical relevance of the differences.

Results: A total of 11 families (34.4%) had no outliers on any parameter, 13 families (40.6%) had outliers on 1 parameter, and 8 families (25%) had outliers on ≥2 parameters. We identified 29 individuals with at least 1 outlying measure (20.4%). Among these, only 2 individuals (1.4%) were significantly different from their siblings for more than 1 measurement. Although the majority of the families did not demonstrate any statistical outlier, the ranges of the measurements were clinically relevant as they might suggest different treatment. For example, the mean range of SNB (Sella-Nasion-B point) angles was 7.23°, and the mean range of MPA was 9.42°.

Conclusion: Although families are generally not dissimilar in their craniofacial characteristics, measurements from siblings cannot be used to predict the measurements of another sibling in a clinically meaningful way.

Keywords: Sibling relations, facial bones, growth, craniofacial, cephalometry

INTRODUCTION

Orthodontic diagnosis and treatment planning in adolescent patients requires an assessment of the individual's growth potential. Skeletal maturity indices utilizing hand-wrist x-rays or lateral cephalograms provide valuable information regarding the timing of the pubertal growth spurt, and population norms have historically been used as a template against which to compare an individual's growth pattern. As Harris discussed in a 1976 editorial, the usefulness of these averages as a growth prediction reference "clearly depends upon the suitability of the population used in constructing the standards as a reference group."[1] The family unit has subsequently

Corresponding author: Leslie A. Will, e-mail: willla@bu.edu

Received: December 6, 2021
Accepted: February 27, 2022
Publication Date: December 30, 2022

been proposed as an appropriate and personalized benchmark by which to measure a patient's growth potential. One study[2] indicated high parent-offspring heritability of maxillofacial variables in both sagittal and vertical dimensions, which corroborates earlier findings by numerous authors[3,4] and has since been confirmed by additional studies[5] on parents and their offspring.

Despite sharing approximately half of their genes, siblings raised together often resemble each other more than statistically expected by genetics, likely due to a shared parental environment, nutritional access, illness exposure, and/or socioeconomic status, among other potential similarities. This has been described in terms of "canalizing selection" wherein potentially disparate genotypes are funneled toward similar phenotypes by the epigenetic landscape.[6] Furthermore, one study demonstrated that half-sibling groups of rodents resembled each other more with age, suggesting a temporal component to both genetic and epigenetic contributions.[7] This has been confirmed in human studies where parental-offspring craniofacial correlations show increases of 72% as children progress to skeletal maturity.[8]

Past studies have shed some light on phenotypic variability among the craniofacial measurements of siblings. A longitudinal study by Harris and Johnson[9] evaluated craniofacial and occlusal variability in 30 same-sex sibships with Class I skeletal patterns and found that craniofacial measurements were more highly correlated than occlusal measurements. These results corroborated a number of prior studies that showed a similar pattern of heritability for craniofacial variables.[10-12] It is unclear whether this correlation is dependent upon the general deviation from the ideal. For instance, King et al.[13] demonstrated that sibling correlation for occlusal variables was significantly higher in sibships with overt malocclusions than in those with ideal occlusions. This could suggest that genetic and/or epigenetic factors that predispose to a significant deviation from norms within a family may be expressed reliably—that is, there may be less intersibling variability as the overall deviant tendency increases.

There have been significant limitations to prior studies conducted on the subject of cephalometric variability among siblings. The majority of studies consider only 2 siblings per family, which provides a low number of relationships. For instance, the previously referenced study by Harris and Johnson[9] utilized only one same-sex sibling per subject and excluded skeletal discrepancies. The same is true of Saunders et al.[14] who found correlations greater than 50% in lower anterior face height, mandibular corpus length, anterior face height, and anterior mandibular height, but only included individual sibling pairs. Manfredi et al.[15] assessed sibling pairs and found a stronger correlation in vertical vs. horizontal measures, but used a subject population age 10–13, prior to the cessation of growth. This potentially ignores the longitudinal effects of genetic and epigenetic components on adult phenotypes.

The aims of this retrospective pilot study were to investigate skeletal craniofacial measurements among groups of at least 4 siblings at the completion of the growth spurt to identify which of these measurements have the strongest correlation between siblings in a family and to determine whether skeletal craniofacial measurements with clinical implications can be reliably predicted among siblings.

METHODS

This research was a pilot study conducted retrospectively using data from the Forsyth Moorrees twin study. The Boston University Medical Campus Institutional Review Board approved the protocol (H-31945). A complete screening of the repository was conducted to identify all families with at least 4 siblings in a family, including only one of a pair of monozygotic twins. In families with dizygotic twins, both twins were included. Out of the total 500 families available in the repository, a total of 46 families were identified who met these criteria.

Lateral cephalograms were obtained for each sibling at the latest available timepoint after peak pubertal growth, as verified by the cervical vertical maturation score (CVMS) and/or hand-wrist skeletal maturity index (SMI), when available. Post-peak pubertal growth was defined as CVMS IV or SMI 9. Once puberty is completed, it is considered that 85–90% of facial growth is complete. Since all siblings were at least 14 years of age, requiring all siblings to have complete growth would be impossible, since the study only took records up to age 18. A total of 14 families were excluded due to skeletal immaturity at the latest available time point for any individual which would have reduced the family size to fewer than 4 siblings.

The final sample included 32 families with a total of 142 individual siblings. Out of this, 77 (54.2%) were female and 65 (45.8%) were male. All individuals ranged from 14 to 18 years of age at the time of radiographic evaluation, and their growth assessments showed them to be after their growth spurt. Twenty-three families (71.8%) included exactly 4 siblings, while the remaining 9 families consisted of 5 or more siblings (5 with 5, 3 with 6, and 1 with 7).

The majority of sibships consisted of at least one pair of dizygotic twins (29/32, 90.6%), both of whom were included. Of these, 5 families included 2 pairs of dizygotic twins, 1 family included 3 pairs of dizygotic twins, and 2 families included a set of dizygotic triplets. The remaining 3 families (9.4%) included one monozygotic twin, so that all 4 siblings in these families were born at different times. Twelve sibships (33.3%) consisted of an even number of males and females, while the remaining 24 sibships did not. In only one instance was the entire sibship the same sex, all female.

For all families, lateral cephalograms were digitized and traced by a single operator (KM) using Dolphin imaging software (Patterson Dental Supply, Chatsworth, CA, USA). A total of 20 linear and angular parameters, including measurements of facial proportion, maxillary position, mandibular position, maxillomandibular relation, and cranial base proportion, were chosen in order to fulfill as many as possible of the following criteria: (1) inclusion in prior heritability literature, (2) widespread use in orthodontic and anthropometric cephalometrics, (3) clinical value to treatment in orthodontics, and (4) easily distinguishable landmarks on records of varying quality. Of these 20 measurements, 6 were identified as having strong clinical relevance to growth prediction and orthodontic treatment planning due to their indication of jaw relations in the sagittal and vertical planes: facial convexity, facial axis of Ricketts, lower facial height, mandibular arc, mandibular plane angle, and SNB angle.

Statistical Analysis

Statistical analysis focused on several approaches to measuring similarities and differences among the groups of siblings, to approach the predictability of sibling measurements. Dixon's Q-test was applied to see if there were any outliers in a family for a given parameter.[16] Dixon's Q-test is defined in terms of gap/range, where the gap is defined as the larger absolute difference between the questionable subject and its 2 closest neighbors, while range encompasses the entire sibship. A sibling was called an outlier if the Q-test value was greater than a Q-critical value at 90%.[17] Manhattan distance (MD) was used to quantify similarity among siblings per parameter.[18] The data is reported in terms of minimum, maximum, mean, median, and range of MD for each family per parameter. This information is descriptive of the pattern of familial clustering, but as there is no critical value, it cannot be used to determine the significance or lack thereof. Scatter plots visually displayed a subject's measure relative to the mean and standard deviation of each parameter to assess the clinical relevance of the differences. These statistical tests did not result in measures of significance, so that no power analysis was calculated.

RESULTS

In this study, siblings were compared only within families. For the 6 major parameters, Dixon's Q-test was performed in order to determine whether any sibling was a significant outlier from the rest of their family. The results are summarized in Table 1 and detailed in supplemental Table 1, which shows a relatively narrow range of outlier variability across the 6 parameters (ranging from 12.5% to 18.7% of families). Eleven families (34.4%) did not demonstrate a single outlying sibling across any of the 6 parameters. In 13 families (40.6%), there was an outlying sibling in only a single measurement. The remaining sibships demonstrated outliers for either 2 measurements (6 families, 18.8%) or 3 measurements (2 families, 6.3%). Interestingly, in the majority of these multiple-outlier families, each measurement demonstrated a different outlying sibling. Only 2 individuals out of 142 (1.4%) were shown to be the outlying sibling in 2 different measurements, and none were the outlying sibling in 3 or more measurements.

Table 1. Dixon's Q-test results, summarized

Parameter Name	Convexity	Facial Axis	LFH	Mandibular Arc	MPA	SNB Angle
# families with significant outlier	4	5	6	5	6	5
% families with significant outlier	12.5	15.6	18.7	15.6	18.7	15.6

LFH, Lower Facial Height; MPA, Mandibular Plane Angle; SNB, Sella – Nasion - B Point Angle

MD was used to demonstrate similarity among siblings per parameter and is summarized in Table 2 as well as detailed in Supplementary Tables 1–7. It can be seen that the range, even within a given parameter, varied widely between families.

Intraclass correlation coefficient (ICC) was used to provide reliability estimates among 3 repeated measures. ICC was greater than 0.96 for each of the 6 major parameters, indicating excellent intra-rater reliability.

DISCUSSION

The familial facial resemblance has long been a topic of discussion and debate, from the notable 16th-century Spanish Habsburg family through today. A number of studies throughout the years have attempted to elucidate the contribution of genetics to craniofacial growth and development. Genetics was previously a focus because the genetic pattern of an individual was considered immutable and thought to demonstrate the underlying framework of development predictably. However, a genotype never exists in a vacuum, and as Waddington et al.[6] have discussed, the functional demands of the environment upon a genetic scaffold are responsible for producing an individual phenotype.[6]

From an orthodontic perspective, this topic has been discussed in modern literature for almost a century. Byron Hughes stated in a 1944 editorial that research has "shown development or growth to be an unfolding design of interrelated morphological and functional items. The development plan is supplied by genetic facts in which the material and technique of application is provided by nurture and environment. Each of these two areas … contributes similarities and differences … within and between individuals."[19] In the immediate biological family, where siblings can be assumed to share approximately 50% of their genetic material, it stands to reason that shared environmental factors acting upon the genetic scaffolds would produce phenotypes that are more similar than genetics alone would suggest. One study confirmed a temporal component to maxillofacial similarity, demonstrating that variability between first-degree relatives decreases over time, as environmental effects have more time to shape the individual.[8]

Table 2. Manhattan distance results, summarized

Parameter	Minimum Range	Maximum Range
Convexity	0.80	10.70
Facial Axis of Ricketts	0.27	5.52
Mandibular Arc	0.40	7.16
Lower Facial Height (Ricketts)	0.13	5.73
Mandibular Plane Angle	0.27	6.12
Sella – Nasion - B Point Angle	0.2	6.68

Indeed, sibling resemblance is a common-sense phenomenon that is encountered regularly, both in daily life and clinical practice. The fact that such resemblance within families is highly variable is also quite evident. Determining the ways in which non-twin siblings' craniofacial structures resemble each other is not merely an intellectual consideration, but a practical one as well. The application of such information would lie in whether or not same-generation first-degree relatives can be utilized to predict the future craniofacial growth pattern of an individual. This is an important and complex clinical question, one which is not likely to have a simple answer. If predictable sibling resemblance does exist, this would be highly relevant to the practice of orthodontics. Evaluation of a patient's older siblings, via records within the same practice or obtained from another orthodontist, could offer significant insight into a growing patient's future morphology and therefore aid in determining the need for early treatment and/or growth modification.

In this study, we chose to concentrate on 6 variables that were considered to have major clinical implications for orthodontic decision making. Angular measurements were chosen over linear measurements due to the lack of reliable quality of the measuring instrument on the analog radiographs, making linear measurements less reliable. In addition, angular measurements take proportion into account and prevent similarities and differences from being determined due to size alone. The anteroposterior position of the maxilla (facial convexity), anteroposterior position of the mandible (SNB angle and mandibular arc), and vertical status of the craniofacial complex (facial axis of Ricketts, lower facial height, and mandibular plane angle) were chosen due to the reliability of the landmarks used for analysis as well as the relative constancy with age after puberty. These measurements are obviously interrelated and none of them describes anteroposterior or vertical status alone, but together give an overall description of an individual facial pattern and help to define treatment goals. In general, it would be expected that a sibling with a facial pattern distinctly different from that of their sibling would be an outlier in more than one measurement, and siblings who appear very similar would demonstrate closely related values in multiple measurements as well.

The data does show a relatively consistent percentage of families with outliers for each of the 6 parameters, with a range of 12.5–18.7% (Table 1). However, these are generally not the same families across categories, and the actual outlying sibling is not generally consistent. In 21 of 32 families (65.6%), there was a statistically significant outlying sibling in at least one measurement. Although 8 of these 21 families (38.1%) demonstrated outliers in 2 or 3 measurements, the large majority of the outliers were different siblings for each parameter. Only 2 individuals out of 142 (1.4%) were the outlying sibling in 2 separate variables (lower facial height and mandibular plane angle; mandibular plane angle and SNB angle, respectively). A further 13 families (40.6%) demonstrated an outlying sibling in only one of the 6 measurements, with no outliers in the remainder. This suggests that facial patterns are not developed as a whole, but rather a sibling can resemble their family in multiple measurements but still be an outlier in another.

The scatter plots of MD for each of the 6 parameters (Figures 1–6) offer a visual display of the values per sibling for each family. In general, a smaller mean, median, and range of MD for a given family reinforces the similarity in measurements across siblings, indicating tighter clustering. This is a subjective delineation, but important nonetheless, as some families show striking similarities across all siblings (i.e., SNB angle in family 24) and the predictability of such clustering would have important clinical ramifications. For the sake of comparison, families with clear visual similarity and who demonstrated a value for MD range below 1 standard deviation of the study population were considered to demonstrate clustering. For any given parameter, the number of families with tight clustering ranged from 3 to 6 (9.3–18.7%), whereas a relatively equivalent number of families demonstrated a significant outlier (range of 4–6 families; 12.5–18.7%; Table 1). Therefore, for a given measurement, there appears to be a similar incidence of families where all siblings resemble each other and families with a statistically significant outlier.

For each parameter, the majority of families showed neither a tight clustering of siblings nor a particular outlier. The average sibship demonstrated a relatively wide range of values across individuals for any given measurement. The distribution of sibling values in relation to published historical norms per parameter is summarized in Table 3. For any given parameter, only 18.8–31.3% of families demonstrated sibling values entirely within 1 standard deviation above or below the normal value. The majority of families, therefore, had at least one sibling with a value that would be considered significantly deviant from the mean. Of these, the majority of families (43.8–62.5%) demonstrated a consistent direction of abnormality, that is, positive or negative values in relation to the mean. However, some families (3.1–9.4%) had at least one sibling with values greater than 1 SD in both the positive and negative direction, indicating vastly different facial patterns that would likely require significantly different orthodontic treatment objectives. Around 12.5–18.8% of families included at least one sibling with a value greater than 2 SD from the mean. In multiple instances, 2 or even 3 sibling values per family fell more than 2 SD from the mean. These families were no more likely to demonstrate a statistically significant outlier than families without such a deviant sibling. However, almost all families with at least 1 sibling more than 2 SD from the mean also included at least 1 sibling within the normal range, that is, within 1 SD. Such a wide range of values despite the absence of a statistical outlier implies a relative continuum across siblings and therefore emphasizes the significant variability possible within a single family.

Many studies have looked at heritability from parents to offspring,[20] and this narrow-sense heritability has often been the primary focus of much of the orthodontic literature concerning craniofacial variability. It is possible that sibships with greater variability in craniofacial measurements came from parents with distinctly different measurements between them, while sibships with less variability had parents who more closely resembled each other. However, Saunders et al.[14] demonstrated that the midparent value explains more of the variation of the offspring than the value from either parent alone. This is

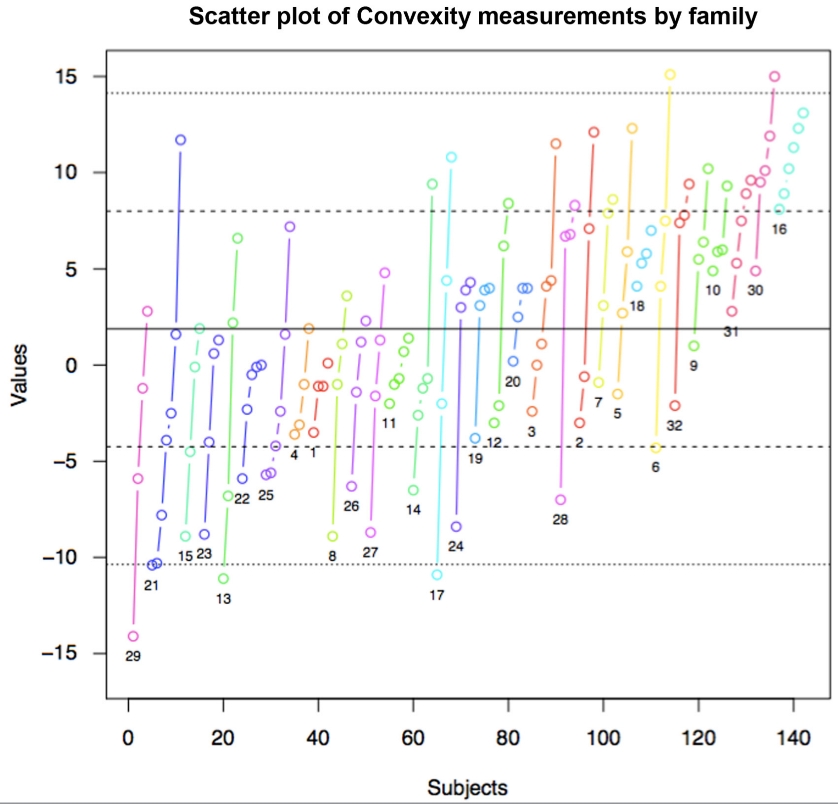

Figure 1. Facial convexity—individual sibling data points grouped according to family. The solid line represents the published population mean. Dashed and dotted lines represent 1 and 2 standard deviations from the mean, respectively.

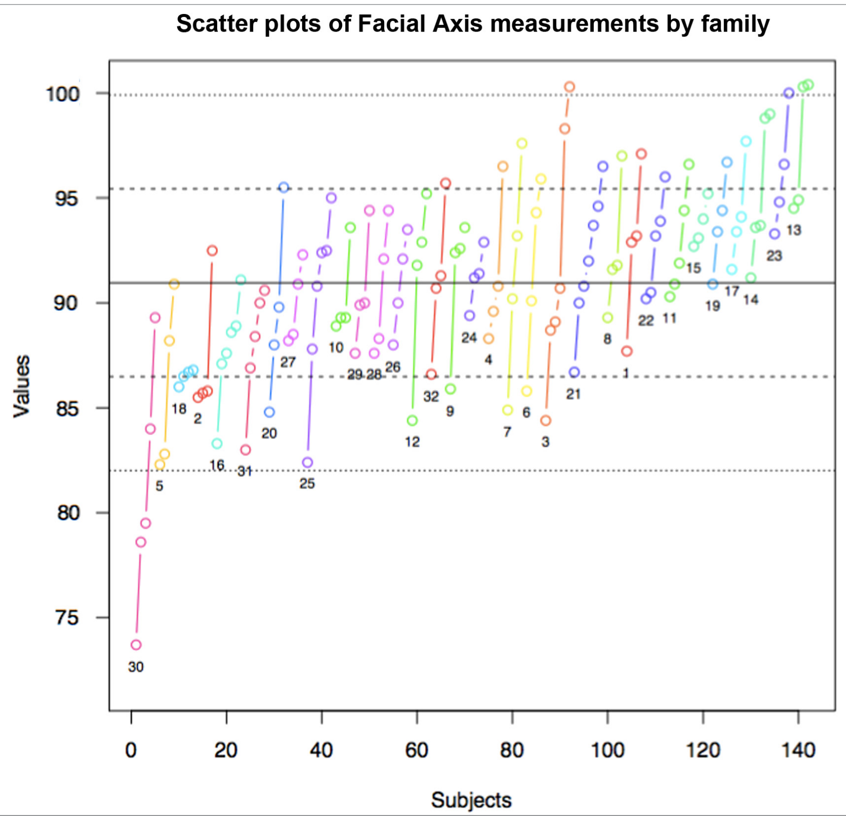

Figure 2. Facial axis of Ricketts—individual sibling data points grouped according to family. The solid line represents the published population mean. Dashed and dotted lines represent 1 and 2 standard deviations from the mean, respectively.

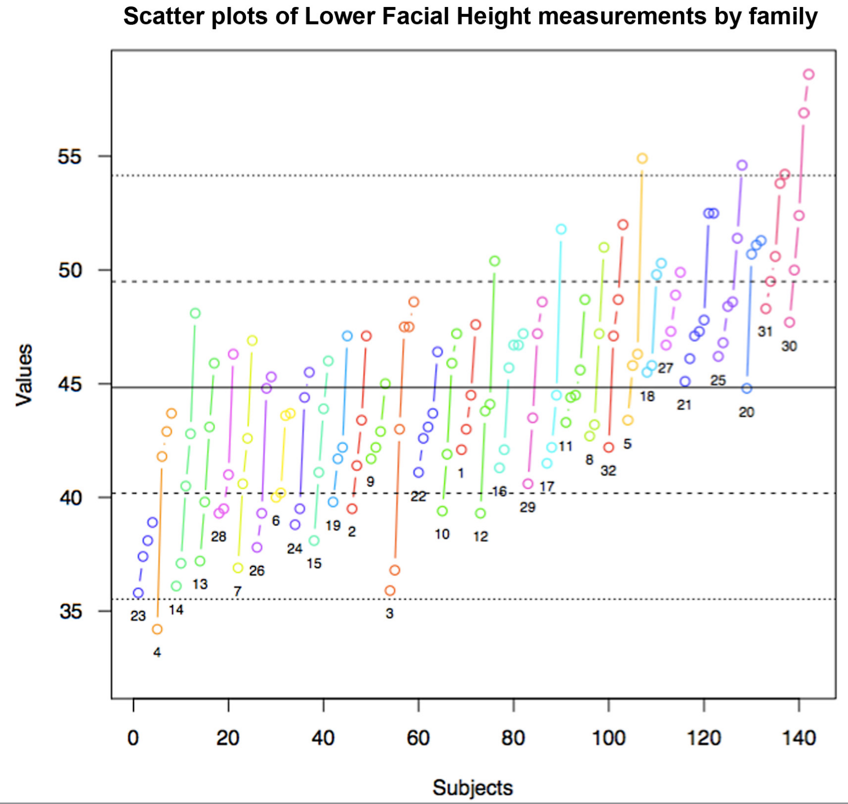

Figure 3. Lower facial height—individual sibling data points grouped according to family. The solid line represents the published population mean. Dashed and dotted lines represent 1 and 2 standard deviations from the mean, respectively.

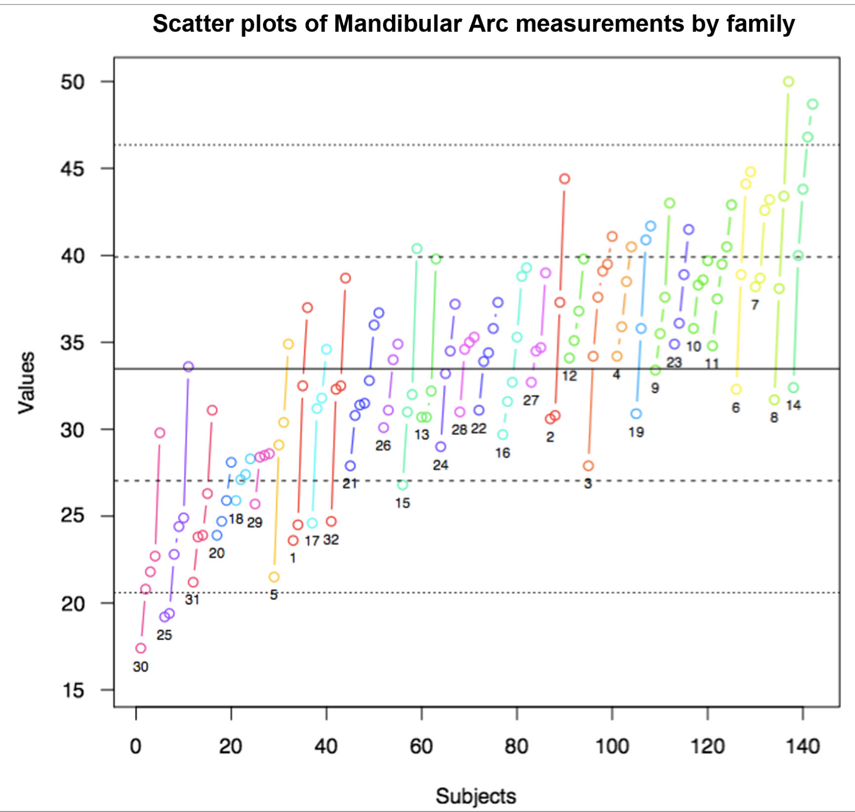

Figure 4. Mandibular arc—individual sibling data points grouped according to family. The solid line represents the published population mean. Dashed and dotted lines represent 1 and 2 standard deviations from the mean, respectively.

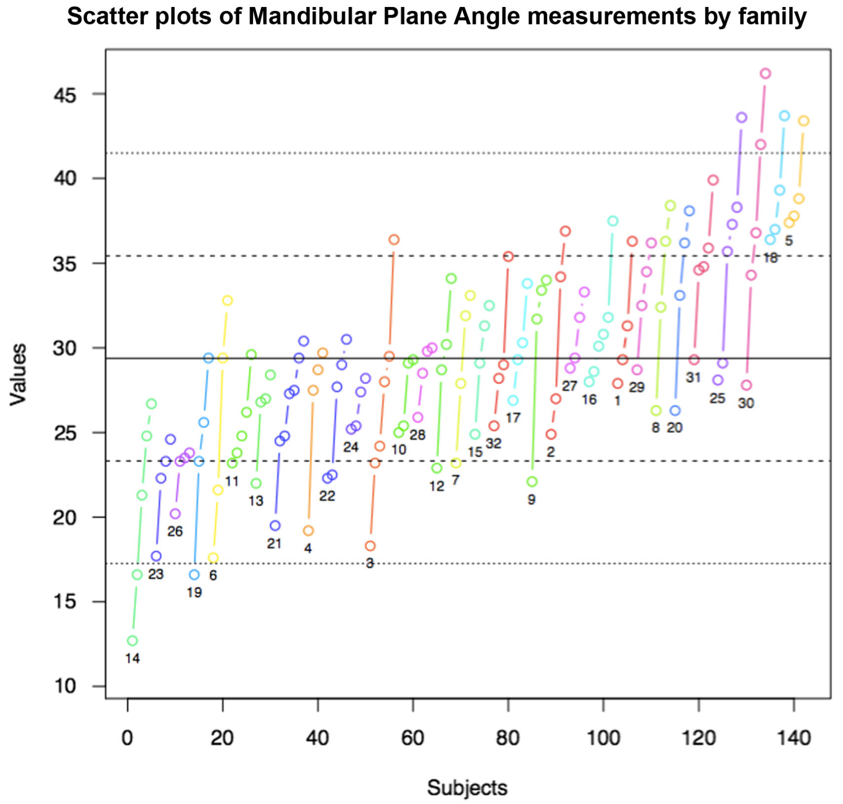

Figure 5. Mandibular plane angle—individual sibling data points grouped according to family. The solid line represents the published population mean. Dashed and dotted lines represent 1 and 2 standard deviations from the mean, respectively.

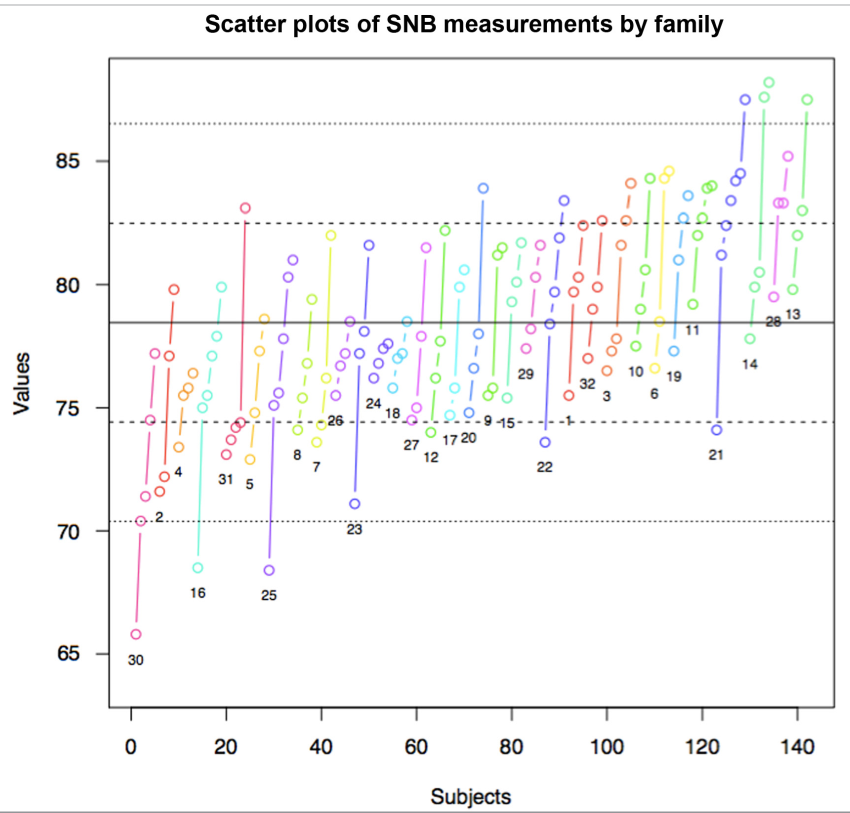

Figure 6. SNB angle—individual sibling data points grouped according to family. The solid line represents published population mean. Dashed and dotted lines represent 1 and 2 standard deviations from the mean, respectively.

Table 3. Distribution of sibling values by published norms per parameter

	Convexity	Facial Axis	Lower Facial Height	Md Arc	Md Plane Angle	SNB Angle
≤1 SD						
# families	6	7	7	10	9	10
% families	18.8	21.9	21.9	31.3	28.1	31.3
≤2 SD unilateral						
# families	18	19	20	17	16	14
% families	56.3	59.4	62.5	53.1	50.0	43.8
≤2 SD bilateral						
# families	3	2	1	1	1	2
% families	9.4	6.3	3.1	3.1	3.1	6.3
>2 SD						
# families	5	4	4	4	6	6
% families	15.6	12.5	12.5	12.5	18.8	18.8

Families are classified into the category occupied by the sibling with the most deviant value. Unilateral indicates the presence of one or more siblings with values $1 < x \leq 2$ SD in only one direction (positive or negative) from the mean. Bilateral indicates one or more siblings with values $1 < x \leq 2$ SD in both directions from the mean.

contrary to a finding by Nakasima et al.[21] who demonstrated high parent-offspring correlation in families with severe Class II or Class III malocclusions. In any respect, from a practical sense, the skeletal and dental measurements of the parents are unlikely to be available to the orthodontist in the same manner that a previously treated siblings may be. Our primary objective was to determine whether siblings can be utilized in a predictive manner in the absence of parental data. For this reason, we determined that parental measurements would not be included in this study.

Prior studies have demonstrated a possible difference in heritability between sexes. Johannsdottir et al.[2] studied craniofacial variability within an Icelandic population and found that males generally showed stronger heritability to their mothers than their fathers, whereas females were affected by both parents equally.[2] We did not differentiate between sexes in this study, as it would have significantly reduced the number of effective siblings per family. However, of the 31 total instances of a statistically significant outlying sibling, in only 4 of these cases (12.9%) was the outlying sibling the sole member of one particular sex within the family. In other words, it does not appear that females are more likely to be significantly different from their male siblings as compared to their female siblings, and vice versa. This is in agreement with the findings of the landmark study by Saunders,[14] which demonstrated a high correlation between siblings regardless of sister-sister, sister-brother, or brother-brother pairings, with brother-sister correlations slightly higher in general.

The present analysis was undertaken as a pilot study in order to assess the predictive value of evaluating multiple siblings in a family. There are several limitations to this study. The sample size was limited to the Forsyth Twin Study data and the number of siblings per family contained therein. We felt that post-pubertal status was important, as it eliminated a significant source of variability that was a limitation in prior literature. The sample size was greatly limited by the presence or absence of records for each sibling at a time point after skeletal maturity was achieved, as numerous additional families (and additional siblings per family) were discarded due to study termination prior to maturity of the youngest siblings. Furthermore, although our sample size of siblings per family is larger than similar studies of this nature[5,9,12] the sample itself consists of a relatively homogeneous Caucasian population. The generalizability of the findings at the national level should be made with caution due to the relatively small size and representativeness of our sample.

An additional limitation is the use solely of two-dimensional images for skeletal measurements. Although these measurements were chosen with regard to their relevance in treatment planning, the use of soft tissue measurements would also contribute to significant information toward detecting family resemblance. Furthermore, the use of three-dimensional images would give a clearer idea of family resemblances; however, the lack of availability of 3-D growth samples prevented us from doing this.

A third limitation pertaining to the measurements chosen for this study involved the configuration of the cephalostat machine used to obtain the lateral cephalograms. A metal rod in the cephalostat was present at a level that prevented the identification of anatomical porion. Therefore, we were unable to use any cephalometric measurements involving Frankfort Horizontal, which utilizes porion, despite the wide use of this reference plane in the orthodontic and anthropologic literature.

From a statistical perspective, one limitation of Dixon's Q-test is that it can only detect a single outlier. In situations where the largest gap between sibling values occurs in the middle of the ordered data, such as when there are 2 distinct clusters of sibling values, the Q-test can produce a false positive despite the lack of a single outlying sibling. In order to mitigate this, the Q-test results were manually checked against the data in order to distinguish true positive outliers from false positives.

CONCLUSION

The present study offers the following insight into the concept of sibling resemblance from a craniofacial perspective:

- Only a small percentage of sibships demonstrated appreciable clustering for any given measurement, and these families were no more likely to show clustering for any other measurement, despite the relative interrelatedness of the variables studied. This runs counter to what we often think as clinicians.

- On the contrary, families with a statistically significant outlier for one variable also had an outlying sibling in a second or third variable 38% of the time. However, with the exception of 2 instances, it was not the same individual who deviated from their siblings in more than one parameter.
- The vast majority of sibships demonstrated neither appreciable clustering nor a significant outlier, and the range of values for these families generally spanned at least 2 standard deviations from the established means.

Therefore, although the majority of families are generally not statistically dissimilar from one another in their craniofacial characteristics, we conclude based on this study that measurements from siblings cannot reliably be used to predict the measurements of another sibling.

Ethics Committee Approval: This study was approved by the Ethics Committee of Boston University Medical Campus University. Number: 71306642-050.01.04.

Informed Consent: An informed consent form was signed by all the patients/parents involved in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – M.M., L.A.W.; Design – Y.Z., M.M., L.A.W.; Supervision – L.A.W.; Data Collection and/or Processing – K.L.M., L.A.W.; Analysis and/or Interpretation – Y.Z., M.M., L.A.W., K.L.M.; Literature Review – K.L.M.; Writing – K.L.M., M.M., L.A.W.; Critical Review – Y.Z., M.M., L.A.W.

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

Funding: The authors declared that this study has received no financial support.

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Supplementary Table 1. Dixon's Q-Test results						
Family #	**Convexity**	**Facial Axis**	**LFH**	**Mandibular Arc**	**MPA**	**SNB Angle**
1	0.667	0.553	0.564	0.597	0.595	0.609
2	0.510	0.957*	0.487	0.514	0.600	0.598
3	0.511	0.478	0.488	0.477	0.381	0.500
4	0.527	0.695	0.800*	0.413	0.790*	0.700
5	0.464	0.628	0.748	0.567	0.767*	0.439
6	0.433	0.426	0.919*	0.528	0.513	0.725
7	0.505	0.417	0.430	0.780*	0.475	0.690
8	0.632	0.675	0.482	0.361	0.504	0.491
9	0.489	0.844*	0.636	0.563	0.807*	0.900*
10	0.750	0.915*	0.513	0.641	0.860*	0.544
11	0.412	0.397	0.574	0.333	0.531	0.583
12	0.728	0.685	0.568	0.526	0.518	0.549
13	0.508	0.915*	0.379	0.835*	0.750	0.584
14	0.635	0.654*	0.442	0.466	0.336	0.683*
15	0.407	0.480	0.380	0.618	0.553	0.619
16	0.260	0.487	0.610*	0.365	0.600*	0.570*
17	0.410	0.590	0.709	0.660	0.507	0.695
18	0.414	0.625	0.833*	0.500	0.603	0.481
19	0.885*	0.431	0.671	0.472	0.523	0.587
20	0.605	0.533	0.908*	0.524	0.576	0.648
21	0.457	0.337	0.635*	0.364	0.459	0.530*
22	0.610	0.466	0.509	0.452	0.634	0.490
23	0.475	0.507	0.516	0.424	0.667	0.581
24	0.898*	0.514	0.731	0.512	0.667	0.429
25	0.434	0.429	0.381	0.604*	0.426	0.532
26	0.570	0.382	0.733	0.604	0.861*	0.433
27	0.526	0.585	0.500	0.683	0.533	0.514
28	0.895*	0.559	0.757	0.837*	0.634	0.667
29	0.485	0.647	0.463	0.931*	0.507	0.500
30	0.455	0.340	0.413	0.573	0.353	0.404
31	0.368	0.513	0.542	0.485	0.500	0.870*
32	0.826*	0.484	0.500	0.543	0.640	0.482

*indicates Q-score greater than Q-critical value at 90%

Supplementary Table 2. Convexity—Manhattan distance

Family	Min.	Max.	Mean	Median	Range
1	1.20	2.80	1.80	1.60	1.60
2	7.60	10.93	8.83	8.40	3.33
3	4.26	10.06	5.71	4.54	5.80
4	2.53	4.47	3.10	2.70	1.93
5	5.67	9.93	7.43	7.07	4.27
6	7.60	13.20	10.27	10.13	5.60
7	4.77	7.43	5.55	5.00	2.67
8	4.87	10.13	6.60	5.70	5.27
9	3.37	6.37	4.75	4.63	3.00
10	1.50	3.70	2.22	1.83	2.20
11	1.28	2.15	1.70	1.63	0.88
12	6.57	8.03	7.08	6.87	1.47
13	8.90	11.83	10.35	10.33	2.93
14	4.45	12.15	6.74	4.80	7.70
15	5.07	8.00	6.13	5.73	2.93
16	1.90	3.06	2.42	2.36	1.16
17	9.37	15.30	11.92	11.50	5.93
18	1.13	1.93	1.53	1.53	0.80
19	2.87	7.47	4.03	2.90	4.60
20	1.77	3.30	2.15	1.77	1.53
21	6.55	17.25	9.09	8.45	10.70
22	2.03	5.18	2.80	2.20	3.15
23	4.90	8.10	5.82	5.13	3.20
24	4.53	12.13	6.50	4.67	7.60
25	4.38	10.46	5.86	4.98	6.08
26	3.73	7.00	4.73	4.10	3.27
27	5.47	10.20	7.23	6.63	4.73
28	5.13	14.27	7.67	5.63	9.13
29	7.20	12.67	9.23	8.53	5.47
30	3.13	6.73	4.52	3.58	3.60
31	2.60	5.03	3.44	3.15	2.43
32	3.97	10.30	5.82	4.50	6.33

Supplementary Table 3. Facial axis of Ricketts—Manhattan distance

Family	Min.	Max.	Mean	Median	Range
1	3.23	6.70	4.75	4.53	3.47
2	2.37	6.83	3.52	2.43	4.47
3	5.42	10.06	7.33	7.02	4.64
4	3.13	6.93	4.30	3.57	3.80
5	4.67	6.47	5.20	4.83	1.80
6	4.77	7.63	5.75	5.30	2.87
7	5.23	8.77	6.85	6.70	3.53
8	2.63	6.10	3.88	3.40	3.47
9	2.63	6.97	3.88	2.97	4.33
10	1.57	4.43	2.35	1.70	2.87
11	2.45	4.72	3.22	3.08	2.27
12	3.97	8.90	5.58	4.73	4.93
13	3.77	4.03	3.85	3.80	0.27
14	3.25	5.08	4.16	4.53	1.83
15	1.13	1.93	1.40	1.27	0.80
16	2.12	5.36	3.03	2.28	3.24
17	2.27	4.67	3.17	2.87	2.40
18	0.33	0.67	0.43	0.37	0.33
19	2.27	3.93	3.07	3.03	1.67
20	4.17	7.97	5.65	5.23	3.80
21	2.88	6.23	3.95	3.48	3.35
22	2.30	4.05	3.00	2.98	1.75
23	2.83	5.10	3.65	3.33	2.27
24	1.23	2.43	1.78	1.73	1.20
25	3.78	9.30	5.25	4.40	5.52
26	2.53	3.87	3.10	3.00	1.33
27	2.17	3.10	2.45	2.27	0.93
28	3.53	5.07	4.03	3.77	1.53
29	2.30	5.23	3.42	3.07	2.93
30	5.25	10.35	7.32	6.38	5.10
31	2.68	5.98	3.66	3.08	3.30
32	3.23	6.17	4.65	4.60	2.93

Supplementary Table 4. Lower Facial Height—Manhattan distance

Family	Min.	Max.	Mean	Median	Range
1	2.33	4.40	3.00	2.63	2.07
2	3.20	5.67	4.13	3.83	2.47
3	5.58	8.78	6.67	6.02	3.20
4	3.53	8.60	4.93	3.80	5.07
5	4.00	9.73	5.83	4.80	5.73
6	2.37	2.50	2.42	2.40	0.13
7	4.00	6.87	5.33	5.23	2.87
8	4.10	6.63	4.82	4.27	2.53
9	1.33	2.73	1.77	1.50	1.40
10	3.93	5.60	4.57	4.37	1.67
11	1.65	4.25	2.40	1.93	2.60
12	3.80	8.00	5.60	5.30	4.20
13	4.00	5.87	4.90	4.87	1.87
14	4.43	8.98	5.94	5.28	4.55
15	3.57	5.57	4.42	4.27	2.00
16	2.30	4.38	2.95	2.50	2.08
17	4.20	9.07	5.53	4.43	4.87
18	2.93	3.27	3.07	3.03	0.33
19	2.60	5.87	3.73	3.23	3.27
20	2.30	6.23	3.32	2.37	3.93
21	2.42	4.85	3.40	2.95	2.43
22	1.60	3.78	2.34	1.75	2.18
23	1.27	2.33	1.67	1.53	1.07
24	3.87	4.60	4.17	4.10	0.73
25	2.64	6.32	3.73	3.52	3.68
26	4.33	5.33	4.67	4.50	1.00
27	1.60	2.27	1.87	1.80	0.67
28	2.83	6.37	3.75	2.90	3.53
29	3.90	5.83	4.62	4.37	1.93
30	4.45	6.85	5.74	5.58	2.40
31	2.55	3.73	3.22	3.35	1.18
32	3.80	7.07	5.17	4.90	3.27

Supplementary Table 5. Mandibular Arc—Manhattan distance

Family	Min.	Max.	Mean	Median	Range
1	7.13	10.13	8.03	7.43	3.00
2	6.77	11.50	7.98	6.83	4.73
3	4.00	10.40	5.56	4.76	6.40
4	2.97	4.30	3.58	3.53	1.33
5	4.90	9.97	6.92	6.40	5.07
6	5.90	10.30	7.12	6.13	4.40
7	2.97	3.37	3.15	3.13	0.40
8	7.87	12.27	10.03	10.00	4.40
9	3.90	7.50	5.15	4.60	3.60
10	1.40	3.07	2.00	1.77	1.67
11	2.78	5.30	3.84	3.28	2.53
12	2.47	4.47	3.13	2.80	2.00
13	3.53	8.60	4.80	3.53	5.07
14	5.78	12.43	7.88	6.73	6.65
15	4.87	10.47	6.97	6.27	5.60
16	3.88	5.84	4.81	4.80	1.96
17	3.53	7.93	5.10	4.47	4.40
18	0.90	1.70	1.25	1.20	0.80
19	5.30	8.57	6.25	5.57	3.27
20	1.80	3.27	2.30	2.07	1.47
21	2.57	5.30	3.64	2.88	2.73
22	2.03	4.25	2.86	2.38	2.23
23	3.13	4.87	3.77	3.53	1.73
24	3.17	5.97	4.32	4.07	2.80
25	4.30	11.46	6.01	5.08	7.16
26	2.57	3.23	2.88	2.87	0.67
27	2.17	5.03	3.18	2.77	2.87
28	1.57	3.97	2.22	1.67	2.40
29	1.00	2.80	1.47	1.03	1.80
30	3.58	9.13	5.34	3.83	5.55
31	3.10	7.30	4.46	3.70	4.20
32	4.73	9.80	7.03	6.80	5.07

Supplementary Table 6. Mandibular Plane Angle—Manhattan distance

Family	Min.	Max.	Mean	Median	Range
1	3.47	6.80	4.53	3.93	3.33
2	6.40	8.20	7.20	7.10	1.80
3	5.64	11.76	7.55	6.14	6.12
4	3.90	9.43	5.45	4.23	5.53
5	2.33	5.40	3.17	2.47	3.07
6	7.67	10.33	8.90	8.80	2.67
7	4.63	7.77	5.62	5.03	3.13
8	5.33	9.40	6.70	6.03	4.07
9	4.53	10.93	6.23	4.73	6.40
10	2.67	2.93	2.77	2.73	0.27
11	2.20	5.10	3.04	2.55	2.90
12	4.23	8.10	5.85	5.53	3.87
13	2.20	5.40	3.23	2.67	3.20
14	5.55	9.65	7.24	6.73	4.10
15	3.27	6.07	4.17	3.67	2.80
16	2.68	7.64	3.85	3.18	4.96
17	2.63	4.97	3.62	3.43	2.33
18	3.20	6.13	4.03	3.40	2.93
19	5.03	9.50	6.78	6.30	4.47
20	4.97	9.50	6.42	5.60	4.53
21	3.08	7.82	4.30	3.65	4.73
22	3.68	5.13	4.58	4.98	1.45
23	2.63	5.70	3.62	3.07	3.07
24	1.67	2.20	1.83	1.73	0.53
25	5.26	9.90	7.11	6.78	4.64
26	1.27	3.33	1.83	1.37	2.07
27	2.30	3.30	2.65	2.50	1.00
28	1.80	3.53	2.27	1.87	1.73
29	3.17	5.70	4.08	3.73	2.53
30	6.53	12.03	8.90	7.83	5.50
31	2.98	7.00	4.50	3.25	4.03
32	3.60	7.87	5.13	4.53	4.27

Supplementary Table 7. SNB Angle—Manhattan distance

Family	Min.	Max.	Mean	Median	Range
1	2.50	5.30	3.55	3.20	2.80
2	4.37	6.17	4.92	4.57	1.80
3	3.34	4.94	3.85	3.64	1.60
4	1.10	2.50	1.55	1.30	1.40
5	2.73	4.00	3.27	3.17	1.27
6	4.60	5.87	4.97	4.70	1.27
7	3.43	7.30	4.52	3.67	3.87
8	2.23	3.97	2.88	2.67	1.73
9	3.80	4.00	3.90	3.90	0.20
10	2.80	5.27	3.67	3.30	2.47
11	1.68	3.95	2.30	1.98	2.28
12	3.23	6.23	4.35	3.97	3.00
13	2.90	5.90	4.02	3.63	3.00
14	4.53	6.75	5.70	6.25	2.23
15	2.37	4.97	3.28	2.90	2.60
16	3.18	8.58	4.49	3.44	5.40
17	3.33	4.07	3.63	3.57	0.73
18	0.97	1.83	1.38	1.37	0.87
19	2.67	5.13	3.43	2.97	2.47
20	3.50	7.43	4.78	4.10	3.93
21	3.08	9.77	4.63	3.37	6.68
22	3.33	7.25	4.62	3.88	3.93
23	3.80	7.87	5.40	4.97	4.07
24	0.67	1.07	0.80	0.73	0.40
25	4.00	9.56	5.39	4.60	5.56
26	1.17	2.03	1.58	1.57	0.87
27	3.30	5.70	3.98	3.47	2.40
28	1.90	4.43	2.85	2.53	2.53
29	2.10	2.97	2.45	2.37	0.87
30	3.88	7.58	5.38	4.65	3.70
31	2.68	9.25	4.14	2.80	6.57
32	2.17	3.97	2.95	2.83	1.80

TURKISH JOURNAL of
ORTHODONTICS

DOI: 10.5152/TurkJOrthod.2022.21157

Original Article

Adaptive Changes in the Posterior Pharyngeal Wall Following Large Retraction of Incisors During Comprehensive Orthodontic Treatment

Ashok Kumar Jena, Venkatachalapathy Anusuya, Jitendra Sharan

Department of Dentistry, All India Institute of Medical Sciences, Sijua, Bhubaneswar, Odisha, India

Cite this article as: Jena AK, Anusuya V, Sharan J. Adaptive changes in the posterior pharyngeal wall following large retraction of incisors during comprehensive orthodontic treatment. *Turk J Orthod.* 2022;35(4):248-254.

Main Points

- The retraction of incisors does not affect the sagittal dimensions of the upper airway.
- The sagittal thickness of the posterior pharyngeal wall decreases significantly as an adaptation to maintain the patency of the upper airway following the retraction of incisors.
- The adaptive changes in the posterior pharyngeal wall occur mainly at the retropalatal and retroglossal regions.
- The adaptive change in the posterior pharyngeal wall can be considered as a risk factor for future sleep-disordered breathing development.

ABSTRACT

Objective: To evaluate the effects of large retraction of incisors on the adaptive changes in the posterior pharyngeal wall and soft palate during comprehensive orthodontic treatment.

Methods: Twenty-seven females with Class I mild crowding or spacing who required non-extraction treatment (group I) and 34 females with Class I bimaxillary dentoalveolar protrusion who required all first premolars extraction for the retraction of their incisors (group II) were included in the study. The effects of non-extraction and incisor retraction following all first premolars extraction orthodontic treatment on the sagittal dimensions of pharyngeal airway passage and posterior pharyngeal wall thickness were evaluated from pre- and post-treatment cephalograms.

Results: The dimensions of pharyngeal airway passage were comparable among the groups. The length of the soft palate increased ($P < .01$) and the thickness of the soft palate decreased ($P < .01$) following retraction of incisors, and the difference between the groups was significant ($P < .05$). The posterior pharyngeal wall thickness was reduced significantly at PPWT2 ($P < .05$), PPWT3 ($P < .001$), PPWT4 ($P < .001$), PPWT5 ($P < .001$), and PPWT6 ($P < .01$) regions following retraction of the incisors, and the difference between the groups was statistically highly significant.

Conclusions: The large retraction of incisors during comprehensive orthodontic treatment in Class I bimaxillary dentoalveolar protrusion malocclusion subjects did not affect the sagittal dimensions of pharyngeal airway passage, but the thickness of the posterior pharyngeal wall reduced significantly as an adaptation to maintain the patency of the upper airway.

Keywords: Bimaxillary protrusion, incisor retraction, pharyngeal airway passage, upper airway, pharyngeal wall thickness, sleep-disordered breathing

INTRODUCTION

Extraction of all first premolars and retraction of incisors is a well-established treatment option for the management of Class I bimaxillary dentoalveolar protrusion malocclusions. The retraction of incisors leads to a reduction of oral volume and the available space for the accommodation of the tongue.[1,2] This often leads to the posterior position of the tongue and reduction of pharyngeal airway passage (PAP) dimensions.[3] Though this proposed mechanism is theoretically acceptable, the reduction of PAP dimensions following retraction of incisors is still

Corresponding author: Ashok Kumar Jena, e-mail: dent_ashok@aiimsbhubaneswar.edu.in

Received: August 11, 2021
Accepted: February 6, 2022
Publication Date:
December 30, 2022

controversial. There are many studies in the literature supporting the reduction of PAP dimensions and volume following retraction of incisors.[4-12] However, a lot of studies also reported no changes in the PAP dimensions after the retraction of incisors.[1,13-16] Although the evaluation of upper airway dimensions by using three-dimensional images is considered the best method, the results are conflicting.[5,14] One study reported extraction orthodontic treatment leads to adaptive changes in the upper airway morphology.[14] As the changes in the upper airway dimensions following extraction orthodontic treatment are confusing and controversial,[1,4-16] there might be compensatory adaptations in the surrounding soft tissue. To the best of our knowledge, there is no study evaluating the adaptive changes in the surrounding soft tissue of the upper airway following maximum retraction of the incisors. Thus, the present study was designed to evaluate the effects of retraction of incisors on the sagittal thickness of the posterior pharyngeal wall among the subjects with Class I bimaxillary dentoalveolar protrusion malocclusions.

METHODS

This retrospective study was conducted in the Division of Orthodontics, Department of Dentistry, All India Institute of Medical Sciences, Bhubaneswar, India. Assuming the mean difference of 0.5 mm in the thickness of posterior pharyngeal wall at the level of oropharynx between the groups, 0.65 mm as standard deviation (SD), 95% Confidence Interval, 80% power, a sample size of 27 in each group was calculated. Open Epi version 3, an open source calculator was used for calculation of sample size. Orthodontic record files of 348 subjects who had completed comprehensive orthodontic treatment between January 2015 and December 2020 were reviewed by one of the authors (AKJ). Of 348, 78 (M = 17, F = 61) subjects met the selection criteria. The inclusion criteria were:

- Age between 18-25 years;
- Class I skeletal relationship;
- Similar vertical facial growth pattern (normodivergent growth; Frankfort mandibular plane angle (FMA), 25˚ ± 5˚);
- Female subjects having Class I malocclusion with mild crowding or spacing (≤4 mm) who were treated by non-extraction treatment;
- Female subjects having Class I bimaxillary dentoalveolar protrusion malocclusions with mild crowding or spacing (≤4 mm) who were treated by all first premolars extraction and had a minimum of 5 mm retraction of maxillary and mandibular incisors; and
- Good quality pre- and post-treatment lateral cephalograms with hard and soft tissue details.

Subjects with a history of comprehensive orthodontic treatment, surgery for pharyngeal pathology and nasal obstruction, snoring, and any systemic disease were excluded.

Of 78 selected subjects, there were only 17 males. Thus, all female subjects (n = 61) were included in the study. Of 61 subjects, 27 subjects who had Class I dental malocclusions with mild crowding or spacing (≤4 mm) on Class I skeletal relationship and treated by non-extraction orthodontic treatment were included in Group I. Group II included the rest of the 34 subjects who had Class I bimaxillary dentoalveolar protrusion malocclusions with mild crowding or spacing (≤4 mm) on Class I skeletal relationship and treated by all first premolars extraction for the retraction of their anterior teeth. Written informed consent had been obtained from each patient for the comprehensive orthodontic treatment and to use their records for various academic and research activities. The present study was approved by the Institute Ethics Committee (T/IM-NF/Dentistry/20/151) and was conducted according to the principles of the Helsinki Declaration.

All the subjects selected for the study had been treated by the same operator (AKJ). The malocclusion in all subjects was corrected by a standard edgewise appliance system (0.018" slot, American Orthodontics, Sheboyan, WI, USA). In Group II subjects, anchorage in the maxillary and mandibular arches was reinforced by the Nance button and lingual arch, respectively, and 2 steps space closure technique was followed. In all subjects, the cephalograms were recorded before the beginning and 1 week after the completion of comprehensive orthodontic treatment. All cephalograms were recorded with the same machine (NewTom GiANO, Imola, Bolanga, Italy) with the same exposure parameters (80 Kvp, 10 mAs, and 1.6 seconds). While recording the lateral cephalograms, subjects were placed in the standing position with Frankfort horizontal plane parallel to the floor and teeth in centric occlusion. The heads of the subjects were kept erect. The cephalograms were exposed at the end-expiration phase of the respiration. Subjects were instructed not to move their heads and tongues and not to

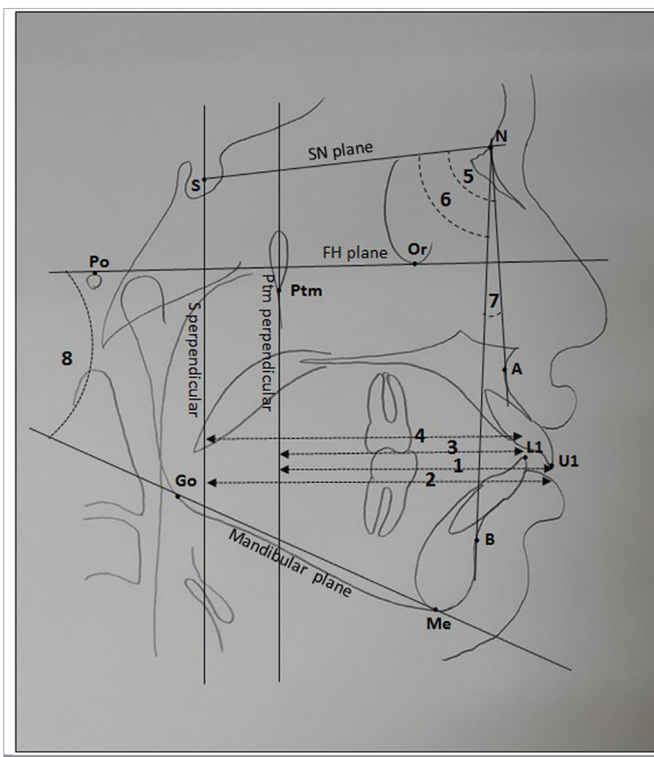

Figure 1. Cephalometric landmarks, reference planes, and linear and angular parameters used for the evaluation of sagittal and vertical jaw relationships and the amount of incisor retraction

swallow during the exposure of cephalograms. All the lateral cephalograms were traced manually by the same evaluator (AKJ).

The method for the evaluation of sagittal and vertical jaw relationships and the amount of maxillary and mandibular incisors retraction are shown in Figure 1. The landmarks were sella (S), nasion (N), porion (Po), orbitale (Or), gonion (Go), Point A (A), Point B (B), menton (Me), pterygomaxillary fissure (Ptm), the tip of upper incisor (U1), and the tip of the lower incisor (L1). The reference planes included SN plane, the line joining S and N; FH plane, the line joining Po and Or; Ptm perpendicular, the perpendicular plane on FH plane at Ptm; S perpendicular, perpendicular plane on FH plane at S; and mandibular plane, the line joining Go and Me. The linear parameters included (1) U1 to Ptm perpendicular, the perpendicular distance from U1 to Ptm perpendicular; (2) U1 to S perpendicular, the perpendicular distance from U1 to S perpendicular; (3) L1 to Ptm perpendicular, the perpendicular distance from L1 to Ptm perpendicular; (4) L1 to S perpendicular, the perpendicular distance from L1 to S perpendicular. The angular parameters considered were (5) SNA, the angle between S, N, and A; (6) SNB, the angle between S, N, and B; (7) ANB, the angle between A, N, and B; (8) FMA, the angle between the FH plane and the mandibular plane.

The sagittal dimensions of PAP were determined according to the method described in previous studies[17,18] and mentioned in Figure 2. The cephalometric landmarks included N, Po, Or, posterior nasal spine (PNS), Ptm, basion (Ba); the tip of soft palate (U), upper pharyngeal wall (UPW), the intersection of line Ptm-Ba and posterior pharyngeal wall; middle pharyngeal wall (MPW), the intersection of perpendicular line on Ptm perpendicular from U with the posterior pharyngeal wall, vallecula (V), and lower pharyngeal wall (LPW), the intersection of perpendicular line on Ptm perpendicular from V with the posterior pharyngeal wall. The FH plane, Ptm perpendicular, and Ba-N plane, the line joining Ba and N were considered as reference planes. Various linear parameters included (1) DNP (Ptm-UPW); (2) HNP, the shortest linear distance from PNS to Ba-N plane; (3) DOP (U-MPW); (4) DHP (V-LPW); (5) soft palate length (SPL) (U-PNS); (6) soft palate thickness (SPT), the maximum thickness of the soft palate. The angular parameter included (7) soft palate inclination (SPI) (Ptm perpendicular × PNS-U), the angle between Ptm perpendicular and the soft palate (PNS-U).

The posterior pharyngeal wall thickness (PPWT) was evaluated according to the method mentioned by Ghodke et al.[18] and Joseph et al.[19] (Figure 3). Various landmarks were anterior nasal spine (ANS), PNS, mid-point of soft palate (MSP; it is the intersection of PNS-U line and a line representing the maximum thickness of soft palate); U, Go, Me, superior-anterior point of C3 vertebra (SC3); inferior-anterior point of C3 vertebra (IC3). Reference planes were (1a) palatal plane (ANS-PNS), (2b) mandibular plane, (3c) anterior tangent to C2 vertebra, a tangent is drawn along the anterior border of C2 vertebra; (4d) the long axis of the soft palate (PNS-U). The linear parameters included (1) PPWT1, the distance from the intersection point of palatal plane and posterior pharyngeal wall to the intersection point of palatal plane and anterior tangent of C2 vertebra; (2) PPWT2, the distance from the intersection point of the line parallel to

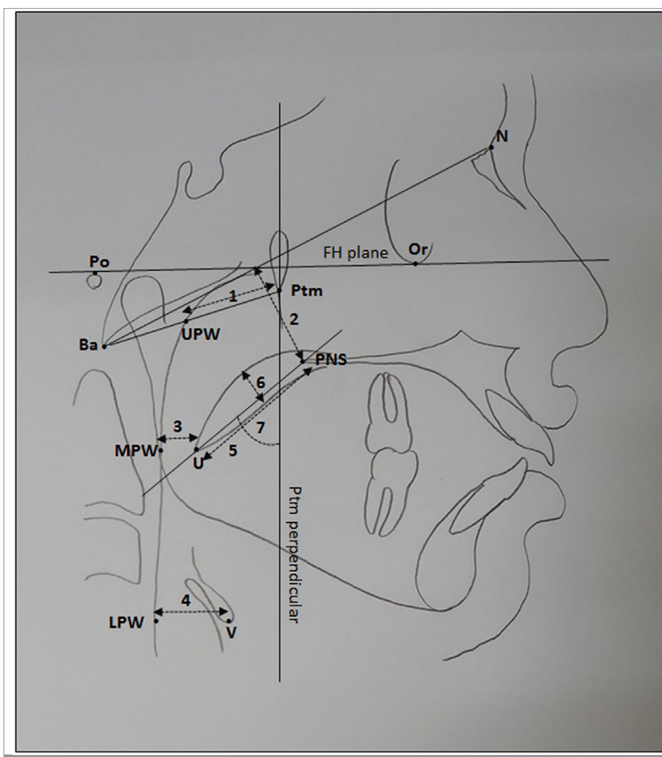

Figure 2. Cephalometric landmarks, reference planes, and linear and angular parameters used for the evaluation of sagittal pharyngeal airway passage dimension changes

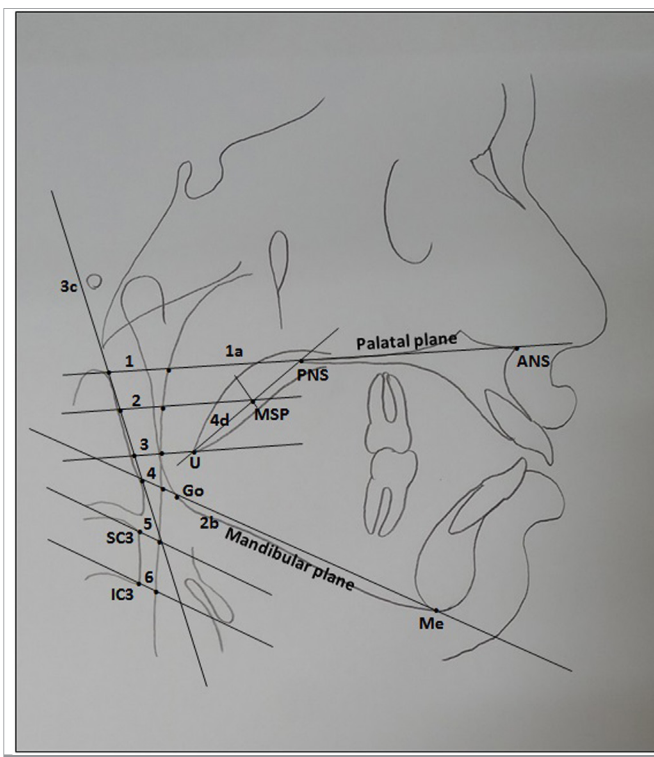

Figure 3. Cephalometric landmarks, reference planes, and linear parameters used for the evaluation of posterior pharyngeal wall thickness change

the palatal plane passing through U and the posterior pharyngeal wall to the intersection point of the same line extended posteriorly and anterior tangent of C2 vertebra; (3) PPWT3, the distance from the intersection point of the line parallel to the palatal plane passing through U and the posterior pharyngeal wall to the intersection point of the same line extended posteriorly and anterior tangent of C2 vertebra; (4) PPWT4, the distance from the intersection point of the mandibular plane and posterior pharyngeal wall to the intersection point of the mandibular plane and anterior tangent of C2 cervical vertebra; (5) PPWT5, the distance from the intersection point of the line parallel to the mandibular plane passing through the superior-anterior point of C3 vertebra and the posterior pharyngeal wall to superior-anterior point of C3 vertebra; (6) PPWT6, the distance from the intersection point of the line parallel to mandibular plane passing through the inferior-anterior point of C3 vertebra and the posterior pharyngeal wall to inferior-anterior point of C3 cervical vertebra.

The linear magnifications of radiographs were corrected and calibrated according to the magnification factor, using the radio-opaque ruler (calibration marker). The linear parameters were measured by digital caliper to the nearest 0.01 mm and protractor to the nearest 0.5° degree for the measurement of angular measurements. All the parameters were measured twice and their mean was considered for the statistical analysis. The assessment of intra-observer error and reproducibility of landmark location and measurement errors was analyzed by retracing the 10 randomly selected cephalograms after a gap of 15 days. The intra-observer reliability of the measurements was calculated by the intraclass correlation coefficient (ICC) for the measurements obtained by the evaluator at both times.

Statistical Analysis

All the statistical analyses were performed in the Statistical Package for the Social Sciences software (for Windows 7, version 25, SPSS, Chicago, Ill, USA). Descriptive statistics were used. Shapiro–Wilk's test was used to examine the normality of the data. The significant changes between pre- and post-treatment values in each group were determined by paired *t*-test. Any significant difference in the changes between the 2 groups was evaluated by an unpaired *t*-test. The *P* value of .05 was considered as the level of significance.

RESULTS

The ICC ranged from 0.96 to 0.99 showing excellent reliability between the measurements. The mean age of the subjects at the beginning of treatment was 21.04 ± 2.08 years and 22.50 ± 3.53 years in Group I and II subjects, respectively ($P = .922$). The mean duration of treatment was 405.96 ± 124.32 days in Group I and 794.5 ± 105.35 days in Group II subjects ($P < .001$). The mean body mass index (BMI) in Group I subjects was 25.16 ± 1.89 kg/m^2 at the beginning and 24.87 ± 1.72 kg/m^2 at the end of treatment ($P = .184$), whereas it was 24.91 ± 1.99 kg/m^2 and 24.78 ± 1.86 kg/m^2 at the beginning and end of treatment, respectively, in Group II subjects ($P = .100$). The mean BMI of the subjects among Group I and II subjects at the beginning ($P = .638$) and end of the treatment ($P = .846$) was comparable. Various parameters for the sagittal and vertical skeletal jaw relationships and the mean retraction of the maxillary and mandibular incisors are mentioned in Table 1. The mean change of SNA, SNB, ANB, and FMA was very minimum during the treatment in each group and the mean differences were statistically comparable. The mean forward or backward movement of upper and lower incisors during the treatment was very minimum in Group I subjects. In Group II subjects, the mean retraction of the upper and lower incisors in relation to the Ptm perpendicular was 6.39 ± 1.18 mm and 5.77 ± 1.26 mm, respectively, and in relation to the Sella (S) perpendicular, it was 6.69 ± 1.67 mm and 6.24 ± 1.47 mm, respectively.

The sagittal PAP dimension changes are described in Table 1. In Group I subjects, non-extraction orthodontic treatment had no significant effect on sagittal PAP dimensions and soft palate. In Group II subjects, incisor retraction did not affect sagittal PAP dimensions, but it had a significant effect on the length ($P < .01$), thickness ($P < .01$), and inclination ($P < .05$) of the soft palate. The SPL increased from 31.67 ± 4.07 mm to 32.64 ± 3.73 mm following the retraction of incisors ($P = .003$). The SPT decreased from 8.60 ± 1.41 mm to 7.66 ± 1.28 mm ($P = .001$) and the SPI increased from 41.76° ± 6.10° to 43.26° ± 5.60° ($P = .041$) by the retraction of incisors in Group II subjects. Between the groups, the comparison showed a significant difference in the changes of SPL and SPT ($P < .05$).

The changes in the sagittal thickness of the posterior pharyngeal wall are described in Table 1. In Group I, non-extraction orthodontic treatment had no significant effect on the sagittal PPWT except PPWT4 ($P < .05$), which decreased from 3.07 ± 0.90 mm to 2.51 ± 0.64 mm following the treatment. But in Group II subjects, all the variables related to the measurement of the sagittal thickness of the posterior pharyngeal wall were decreased significantly following the retraction of the incisors except PPWT1. The inter-group comparison showed a statistically significant difference for PPWT2 ($P < .05$), PPWT3 ($P < .001$), PPWT4 ($P < .01$), and PPWT5 ($P < .001$) changes.

DISCUSSION

There are many diagnostic aids for the evaluation of PAP dimensions and sagittal thickness of the posterior pharyngeal wall. However, lateral cephalograms are the most commonly used one. Miles et al.[20] reported high reliability of cephalometric landmarks and measurements for the same. The commonly used cephalometric landmarks for the evaluation of airway structures can also be reliably identified.[21] Thus, cephalograms are still used widely to evaluate the sagittal dimensions of the upper airway.[17,18,22] The American Association of Orthodontists' white paper on obstructive sleep apnea and orthodontics suggested that 3D evaluation of the upper airway is ideal for the evaluation of upper airway dimensions.[23] However, the primary outcome measure in the present study was to evaluate the sagittal thickness of the posterior pharyngeal wall which is a 2D variable, so lateral cephalograms were considered as an appropriate tool for the same outcome measure.

Table 1. Comparison of skeletal, dental, pharyngeal variables at pre- and post-treatment within groups and comparison of treatment changes between groups

Variables	Group-I (Non-extraction) (n = 27)				Group-II (Extraction) (n = 34)				Comparison of Mean Differences Gr. I vs. Gr. II
	Pre-Treatment Mean ± SD	Post-Treatment Mean ± SD	Difference Mean ± SD	Significance (*P* Value)	Pre-Treatment Mean ± SD	Post-Treatment Mean ± SD	Difference Mean ± SD	Significance (*P* value)	Significance (*P* value)
SNA (°)	82.26 ± 2.04	82.48 ± 1.96	0.22 ± 1.01	0.265 ^{NS}	82.18 ± 1.89	82.26 ± 2.46	0.08 ± 1.35	.707 ^{NS}	.248 ^{NS}
SNB (°)	80.22 ± 1.92	80.56 ± 2.24	0.33 ± 1.41	0.232 ^{NS}	79.59 ± 2.42	80.18 ± 2.71	0.58 ± 1.25	.010*	.460 ^{NS}
ANB (°)	2.00 ± 1.00	1.93 ± 1.26	−0.07 ± 1.10	0.731 ^{NS}	2.59 ± 1.25	2.09 ± 1.21	−0.50 ± 1.05	.009**	.130 ^{NS}
FMA (°)	22.30 ± 1.79	22.48 ± 1.84	0.18 ± 0.96	0.327 ^{NS}	25.41 ± 2.06	25.15 ± 2.06	−0.26 ± 1.37	.271 ^{NS}	.155 ^{NS}
U1-Ptm perpendicular (mm)	54.80 ± 4.24	54.47 ± 4.03	−0.33 ± 2.31	0.465 ^{NS}	57.49 ± 3.69	51.10 ± 3.34	−6.39 ± 1.18	.000***	.000***
U1-S perpendicular (mm)	73.21 ± 4.38	72.52 ± 4.12	−0.69 ± 2.78	0.206 ^{NS}	74.35 ± 5.37	67.65 ± 5.13	−6.69 ± 1.67	.000***	.000***
L1-Ptm perpendicular (mm)	50.70 ± 4.29	51.03 ± 3.94	0.23 ± 3.22	0604 ^{NS}	53.41 ± 4.06	47.64 ± 3.83	−5.77 ± 1.26	.000***	.000***
L1-S perpendicular (mm)	69.30 ± 4.36	69.75 ± 3.81	0.45 ± 2.46	0.347 ^{NS}	70.65 ± 5.38	64.41 ± 5.05	−6.24 ± 1.47	.000***	.000***
DNP (mm) (Ptm-UPW)	21.28 ± 3.09	20.37 ± 3.24	−0.91 ± 2.42	0.062 ^{NS}	19.35 ± 4.58	18.91 ± 5.32	−0.44 ± 2.43	.290 ^{NS}	.034*
HNP (mm) (PNS to Ba-N plane)	21.57 ± 2.24	21.85 ± 2.09	0.28 ± 0.82	0.090 ^{NS}	22.13 ± 2.49	21.82 ± 2.32	−0.31 ± 1.47	.229 ^{NS}	.068 ^{NS}
DOP (mm) (U-MPW)	10.23 ± 2.90	10.20±2.69	−0.03 ± 1.14	0.889 ^{NS}	10.50 ± 3.48	10.27 ± 3.39	−0.23 ± 2.04	.514 ^{NS}	.651 ^{NS}
DHP (mm) (V-LPW)	14.77 ± 2.50	14.94 ± 2.29	0.16 ± 1.70	0.624 ^{NS}	14.72 ± 2.65	14.33 ± 2.23	−0.39 ± 1.65	.179 ^{NS}	.206 ^{NS}
SPL (mm) (U-PNS)	30.96 ± 3.69	30.87 ± 3.28	−0.08 ± 2.22	0.821 ^{NS}	31.67 ± 4.07	32.64 ± 3.73	0.96 ± 1.50	.003**	.040*
SPT (mm) (Maximum thickness of the soft palate)	8.80 ± 1.07	8.61 ± 1.23	−0.18 ± 0.86	0.270 ^{NS}	8.60 ± 1.41	7.66 ± 1.28	−0.94 ± 1.50	.001**	.024*
SPI (°) (Ptm per × PNS-U)	38.41 ± 4.34	38.41 ± 5.64	0.00 ± 3.85	1.000 ^{NS}	41.76 ± 6.10	43.26 ± 5.60	1.5 ± 4.11	.041*	.151 ^{NS}
PPWT1 (mm)	16.16 ± 2.47	16.47 ± 2.41	0.30 ± 2.16	0.468 ^{NS}	16.56 ± 2.17	16.28 ± 2.20	−0.28 ± 2.19	.459 ^{NS}	.300 ^{NS}
PPWT2 (mm)	8.12 ± 0.96	8.06 ± 1.05	−0.06 ± 0.83	0.699 ^{NS}	9.38 ± 2.33	8.44 ± 1.58	−0.94 ± 2.10	.013*	.044*
PPWT3 (mm)	4.12 ± 0.77	3.88 ± 0.77	−0.23 ± 0.66	0.084 ^{NS}	5.23 ± 0.88	3.99 ± 0.91	−1.24 ± 1.14	.000***	.000***
PPWT4 (mm)	3.07 ± 0.90	2.51 ± 0.64	−0.56 ± 1.30	0.033*	4.25 ± 1.27	2.73 ± 0.95	−1.51 ± 1.36	.000***	.008**
PPWT5 (mm)	3.80 ± 0.54	3.92±0.50	0.12 ± 0.55	0.265 ^{NS}	4.71 ± 0.70	3.73 ± 0.52	−0.98 ± 0.70	.000***	.000***
PPWT6 (mm)	3.76 ± 0.70	3.58 ± 0.57	−0.18 ± 0.74	0.204 ^{NS}	4.31 ± 0.65	3.89 ± 0.45	−0.42 ± 0.64	.001**	.188 ^{NS}

$^{*}P < .05$; $^{**}P < .01$; $^{***}P < .001$.

ANB, angle between "A," "N," and "B"; DHP, depth of the hypopharynx; DNP, depth of the nasopharynx; DOP, depth of the oropharynx; FMA, Frankfort mandibular plane angle; HNP, height of the nasopharynx; L1-Ptm perpendicular, perpendicular distance from L1 to Ptm perpendicular; L1-S perpendicular, perpendicular distance from L1 to S perpendicular; NS, non-significant; PPWT1, posterior pharyngeal wall thickness at nasopharyngeal space 1; PPWT2, posterior pharyngeal wall thickness at nasopharyngeal space 2; PPWT3, posterior pharyngeal wall thickness at oropharyngeal space 1; PPWT4, posterior pharyngeal wall thickness at oropharyngeal space 2; PPWT5, posterior pharyngeal wall thickness at hypopharyngeal space 1; PPWT6, posterior pharyngeal wall thickness at hypopharyngeal space 2; SD, standard deviation; SNA, angle between "S," "N," and "A"; it represents the anteroposterior position of the maxilla in relation to the anterior cranial base; SNB, angle between "S," "N," and "B"; it represents the anteroposterior position of the mandible in relation to the anterior cranial base; SPI, soft palate inclination; SPL, soft palate length; SPT, soft palate thickness; U1-Ptm perpendicular, the perpendicular distance from U1 to Ptm perpendicular; U1-S perpendicular, perpendicular distance from U1 to S perpendicular.

The effects of incisor retraction following all first premolars extraction among Class I bimaxillary dentoalveolar protrusion malocclusion subjects on PAP is controversial.[24-26] Few studies reported a decrease in sagittal PAP dimensions following incisor retraction in Class I bimaxillary dentoalveolar protrusion malocclusion subjects.[4-10,12] The retraction of the anterior teeth resulted in the dorsal movement of the anterior boundary of the oral cavity and enforced the tongue backward, resulting in the upper airway diminishing in size, especially in the base of the tongue and next in the back of the soft palate.[4,6,9,13] However, the present study did not find any change in the sagittal PAP dimensions following retraction of incisors, and the changes were also comparable to non-extraction treatment subjects. Similar to the observations of the present study, many previous studies also reported no effect of incisor retraction on the sagittal PAP dimensions among adolescents[11,13,27] and in adults.[1,15,27,28] The growth of bone and soft tissue surrounding the upper airway[13,27] and regression of the lymphoid tissue[10] among adolescents probably mask the changes in the pharynx by the incisors' retraction. A greater rate of changes in the soft-tissue measurements of the posterior pharyngeal wall occurs between 6 and 9 years and between 12 and 15 years.[29] Thus, all the subjects above 18 years were included in the present study to ensure that the oropharyngeal structures had reached the adult size and the effect from growth would not affect the result. Also, many previous studies reported no effect of incisors retraction on the sagittal dimensions of PAP in adult subjects with Class I bimaxillary dentoalveolar protrusion malocclusions.[1,15,25,28] Zhang et al.[14] observed that extraction orthodontic treatment in adults leads to widening of the upper airway in the lateral or transverse dimension to maintain its patency in the sagittal dimension. But, Sun et al.[30] noticed that first premolar extraction treatment could change the shape of oropharyngeal airway passage only to some extent. However, 3D CBCT evaluation of upper airway revealed that orthodontic treatment with premolar extraction did not affect sagittal and transverse dimensions, minimal cross-sectional area, and volume in the nasopharyngeal, retropalatal, or retroglossal regions of the upper airway in adult patients.[15] Thus, the surrounding soft tissues might have some adaptive changes for maintaining the upper airway dimensions after incisors retraction among adult subjects. Marşan et al.[31] observed that a more backward position of the tongue following large incisor retraction probably influences the soft palate and posterior pharyngeal walls to have adaptive changes. Previously, Zhang et al.[14] have also observed that the effect of extraction treatment on the upper airway seems to be an adaptive change in the airway morphology, rather than a decrease in the airway size.

The current study revealed that there are no changes in the soft palate dimensions in non-extraction subjects. But the length and thickness of the soft palate were increased and decreased, respectively, following retraction of incisors. The retraction of incisors might push the tongue backward and compressed the soft palate, thus resulting in a decrease in its thickness and an increase in its length. Further, no effect of non-extraction orthodontic treatment on the PPWT was observed, whereas it decreased significantly following incisor retractions among Class I bimaxillary malocclusions subjects. This could be an adaptive change in the posterior pharyngeal wall to maintain the sufficient patency of the upper airway. The loss of fat from the posterior pharyngeal wall might result in the reduction in its thickness. It was observed that the reduction of the PPWT was maximum at retropalatal and retroglossal regions compared to other regions. Such an adaptive change in the posterior pharyngeal wall may be a risk factor for the future development of sleep-disordered breathing, particularly when an individual becomes obese. The excess deposition of fat in the pharyngeal wall during adulthood can lead to constriction of the upper airway passage leading to the development of sleep-disordered breathing.

A systematic review reveals that bicuspid extraction and incisor retraction leads to narrowing of the upper airway in Asian adults and late adolescents.[26] Although the present study did not find any significant narrowing of the upper airway, it revealed that significant adaptations of the soft tissues surrounding the upper airway take place following bicuspid extraction and incisor retraction in Class I bimaxillary dentoalveolar protrusion malocclusion subjects. Also, this was a retrospective cross-sectional study based on lateral cephalograms, which cannot tell about the patient's subjective symptoms related to the breathing, casualty of orthodontic treatment, and 3D airway changes. However, the significance of this is to present clues of the PPWT changes following the retraction of the incisors during comprehensive orthodontic treatment. The present study included only female subjects, thus further investigations on males are needed to confirm the above conclusions and also longitudinal evaluations are needed to identify the long-term changes in the posterior pharyngeal wall following large retraction of the incisors.

The retraction of the incisors can be a risk factor for the future development of sleep-disordered breathing. Thus, before deciding about premolars extraction and large retraction of incisors, patients sleeping and breathing, and the family tendency for sleep-disordered breathing may be evaluated.

CONCLUSION

The following conclusions were drawn from the present study:

- The retraction of incisors in Class I bimaxillary dentoalveolar protrusion malocclusion subjects did not affect the sagittal dimensions of the pharyngeal airway passage.
- The thickness of the soft palate and posterior pharyngeal wall reduced as an adaptive change following the retraction of the incisors in Class I bimaxillary dentoalveolar protrusion malocclusion subjects.
- The adaptive change in the posterior pharyngeal wall was mainly at the retropalatal and retroglossal regions compared to other regions.

Ethics Committee Approval: This study was approved by the Institute Ethics Committee, All India Institute of Medical Sciences, Bhubaneswar (T/IM-NF/Dentistry/20/151) and was conducted according to the principles of the Helsinki Declaration.

Informed Consent: Written informed consent was obtained from each patient for the comprehensive orthodontic treatment and to use their records for various academic and research activities.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - A.K.J.; Design - A.K.J., J.S.; Supervision - A.K.J.; Materials - A.K.J.; Data Collection and/or Processing - A.K.J., A.V., J.S.; Analysis and/or Interpretation - A.K.J., J.S.; Literature Review - A.V., J.S.; Writing - A.K.J., A.V., J.S.; Critical Review - A.K.J., J.S.

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

Funding: The authors declared that this study has received no financial support.

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TURKISH JOURNAL of ORTHODONTICS

DOI: 10.5152/TurkJOrthod.2022.21209

Original Article

Comparison of Tie Wing Fracture Resistance of Differing Ceramic Brackets

Mary Kate James[1], Qingzhao Yu[2], Htwe Mon[3], Xiaoming Xu[3], Alli Blanchard[4], Paul Armbruster[4], Richard W. Ballard[4]

[1]Private Practice of Orthodontics, Houston, TX, USA
[2]Department of Biostatistics, LSU Health Sciences Center, New Orleans, LA, USA
[3]Department of Prosthodontics, LSU Health Sciences Center, New Orleans, LA, USA
[4]Department of Orthodontics, LSU Health Sciences Center, New Orleans, LA, USA

Cite this article as: Kate James M, Yu Q, Mon H, et al. Comparison of tie wing fracture resistance of differing ceramic brackets. *Turk J Orthod.* 2022;35(4): 255-259.

Main Points

- This study found significant differences concerning tie wing facture resistance.
- 3M Clarity brackets had the highest resistance to tie wing fracture.
- Dentsply Ovation S had the lowest resistance to tie wing fracture.

ABSTRACT

Objective: The aim of this study was to compare the tie wing fracture resistance of 4 different manufacturers' ceramic brackets currently on the market.

Methods: The tie wings of ceramic brackets from 4 manufacturers were tested with 10 samples in each group. The brackets were Ormco Symetri, 3M Clarity, American Radiance Plus, and Dentsply Ovation S. The brackets were mounted and fixed in a universal testing machine. A stainless steel ligature wire was looped around a tie wing and the mean tensile strength was both tested and recorded.

Results: There was a significant overall difference in tensile strength among the 4 groups ($P < .0001$) with the 3M Clarity brackets having the highest MPa. When the groups were compared to each other, they also showed a significant difference in mean tensile strength with the exception being the American Radiance Plus and Ormco Symetri brackets.

Conclusion: Test results concluded that the 3M Clarity brackets had the highest resistance to tie wing fracture, while the Dentsply Ovation S brackets had the lowest resistance.

Keywords: Fracture resistance, ceramic orthodontic brackets, tie wing fracture, monocrystalline, polycrystalline

INTRODUCTION

As interest in orthodontic treatment has increased over recent years, the desire for esthetic treatment options has also increased.[1] Many options have arisen including the use of clear aligner therapy, lingual brackets, and ceramic brackets as alternatives to the traditional metal bracket. It is not uncommon for many patients to request ceramic brackets due to the advantage of being white or clear and blending with the surface of the enamel.[2] Although these brackets are more esthetic, they do have a higher susceptibility and frequency of fracture, especially the tie wings, as compared to traditional metal brackets as ceramic material lacks ductility.[1,2] Research has been conducted testing ceramic bracket fracture strength using a variety of forces: tipping, torsion, shear, and impact.[2,3-9] A frequent area of fracture of ceramic brackets occurs at the tie wing or at the junction of the tie wing and base.[2,10] When a tie wing fractures, the bracket needs to be replaced as it creates difficulties in ligating the archwire, fully engaging the archwire in the slot which affects the expression of the bracket prescription, and the ability to attach auxiliaries such as powerchain or elastics. In addition, a bracket

Corresponding author: Richard W. Ballard, e-mail: rball1@lsuhsc.edu

Received: October 6, 2021
Accepted: February 11, 2022
Publication Date: December 30, 2022

with a tie wing fracture has a higher likelihood of a fracture of the bracket which also necessitates bracket replacement.[11] The tie wing fracture and the additional bracket fracture also pose an aspiration hazard for the patient.[12] Because of these issues, it is important to test the fracture resistance and tensile strength of tie wings of these bracket types.[2]

Ceramic brackets are manufactured in either a monocrystalline or polycrystalline state and the manufacturing process may play a role in the varying degrees of resistance to fracture.[13] Monocrystalline (single crystal) brackets are manufactured using aluminum oxide (Al_2O_3) that is heated which causes the particles to melt. The Al_2O_3 mass is then cooled, allowing for controlled crystallization forming 1 single crystal. The brackets are then milled from this crystal using diamond cutting tools. Once formed, they are further heat treated to remove any impurities.[13,14] This process is more expensive than forming a polycrystalline bracket.[13] Producing brackets in this manner results in a decreased likelihood of fracture due to fewer impurities but does not eliminate fracture altogether because the milling process can induce stress which results in brackets that are more prone to fracture.[14]

Polycrystalline brackets are typically produced by a ceramic injection molding technique. In this technique, the Al_2O_3 particles are mixed with a binder and the mixture is forced into a bracket mold through pressurization. Following this, a sintering process occurs in which the mold is heated, not melted, and the binder burns out. The bracket is then machined and heat treated to remove surface imperfections and stresses that occur during the cutting process.[13] The advantage to producing brackets in this manner is that they can be produced quickly, more cheaply, and in bulk.[14,15] However, manufacturing brackets in this manner produces defects at grain boundaries, inducing impurities, which increases its propensity to fracturing.[14] When cracks do occur in polycrystalline brackets, the propagation of the crack occurs more slowly due to the grain boundaries as opposed to a monocrystalline bracket in which the fracture occurs all at once.[16]

In addition to the propensity to fracture, an orthodontist may also consider the translucency of the bracket. As a result of the different manufacturing processes, monocrystalline and polycrystalline brackets have different optical properties. A single-crystal bracket is more translucent as it has less tendency to refract light because of fewer impurities introduced during its manufacturing process. The polycrystalline brackets, with more impurities, appear more opaque.[14]

A PubMed search utilizing "ceramic bracket tie-wing fracture" yielded only 3 articles published since 2005. Using ceramic brackets with a higher tie wing resistance to fracture benefits both the patient and the treating orthodontist. A bracket with a fractured tie wing would lead to an increase in the chair time in order to replace the bracket, an increase in time away from work or school, a potential increase in total treatment time for the patient, a potential increase in the risk of enamel removal from the tooth surface each time a bracket needs to be replaced, and the additional expense of replacing a broken bracket. According to Dr. Sondhi in 2000, in a best-case scenario, a single-bond failure can result in a 20-30 minute loss in chair time and a cost of \$70-\$80 to the practice.[17] That cost would be even greater today.

This laboratory study sought to determine the tie wing fracture resistance of 4 different manufacturers' ceramic brackets when a force is placed directly under the tie wing. The results of this study will add to the data regarding the tie wing failure of ceramic brackets allowing orthodontists to make more informed decisions on which ceramic brackets they will use to optimize practice efficiency and minimize the amount of risk to the patient.

METHODS

The study was approved by the Institutional Review Board of Louisiana State University Health Sciences Center of New Orleans (IBC #19024). Four different manufacturers' ceramic brackets were selected to test their tie wing fracture resistance. Ten maxillary right 0.022-inch slot central incisor brackets from each of the 4 manufacturers underwent fracture testing of their distogingival tie wings. The sample brackets included polycrystalline Ormco Symetri (Ormco, Orange, Calif, USA), 3M Clarity (3M, Monrovia, Calif, USA), Dentsply Ovation S (Dentsply, York, Pa, USA), and monocrystalline American Radiance Plus (AO, Sheboygan, Wis, USA). 3M Clarity brackets were chosen as a comparison bracket because they have been available for many years and have been the subject of much bracket research. The remaining 3 brackets were chosen as they are newer to the market and lack published data concerning their properties and performance behavior.

The sample brackets were bonded to stainless steel washers utilizing a 2-part epoxy system, JB Weld (JB Weld, Sulphur Springs, Tex, USA). It achieves an initial set after 4-6 hours and a full cure is reached within 15-24 hours. When fully cured, it has a tensile strength of 5020 PSI. The epoxy was mixed according to the manufacturer's recommendations, and a thin layer was placed on each washer. The ceramic brackets were placed on the epoxy using cotton pliers and allowed to achieve a full cure of 24 hours. Each bracket was mounted with the distal gingival tie wing facing the outer surface of the washer and as close to the edge of the washer as possible (Figure 1). Care was taken to ensure that

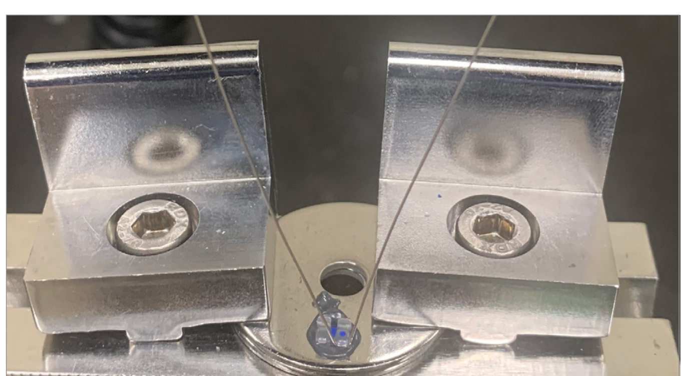

Figure 1. Bracket mounting with the steel ligature engaged under the tie wing

no epoxy flowed over the base of the ceramic brackets or under the tie wings as to avoid compromising the ability to place a steel ligature under the tie wings or further reinforce its strength.

The methodology of this research was based on a previous study by Johnson and a previous study by Sanchez with some modifications.[2,18] This study utilized the sample size calculation of the Johnson study which found the need of 10 samples per group.[2] Using a universal testing machine (Instron 5566, Norwood, Mass, USA), the study tested ceramic bracket tie wing tensile strength, defined as the maximum load that a material can support without fracture when being stretched, divided by the original cross-sectional area of the material.[2] The mechanical testing of the tie wings utilized a 0.012-inch stainless steel ligature wire looped under the distal gingival tie wing of each sample. The looped ligature wire was secured firmly around a grooved rod which was placed through the Instron machine load cell (10 kN) to ensure that the ligature did not fail or slip (Figure 2). A new identical wire was used for each group. The stainless steel washers were securely clamped into place. A vertical tensile force was applied via the ligature wire at a crosshead speed of 5 mm/min until fracture. The tensile force/load at failure was recorded with Instron's Bluehill 3® software (Instron). The samples were not subjected to any methodology that mimicked the intraoral environment prior to testing because Alexopoulou et al.[19] found no change in the mechanical properties of monocrystalline or polycrystalline brackets following intraoral aging.

Fracture strength, reported in megapascals (MPa), was calculated by dividing the maximal tensile force in Newtons (N) by the original cross-sectional area of the tie wing (mm^2).

Statistical Analysis

The objective of the analyses was to compare the tie wing fracture resistance of ceramic brackets of different brands (10 samples per group). The homogeneity of variance assumption was tested first. If the assumption was violated, the Welch ANOVA tests were used to test the overall difference. Post hoc tests were used to provide pairwise comparisons and pairwise *P*-values were adjusted for the multiple comparison using the Tukey method. In addition, non-parametric tests (Kruskal–Wallis test with Dwass-Steel-Critchlow-Fligner method (DSCF) procedure for pairwise comparisons) were used to confirm the results for small sample sizes. All analyses were performed using Statistical Analysis System (SAS) (version 9.4, Cary, NC, USA).

Figure 2. Tensile strength setup of the specimen

RESULTS

The descriptive analysis of tensile strength at peak local maximum for each group is shown in Table 1. The Welch analysis of variance (ANOVA) test results indicated that there was a significant overall difference between the 4 groups in regard to their mean tensile strength at peak local maximum (MPa) with a *P*-value of less than .0001 (Table 2). The brackets from 3M showed a significantly larger mean tensile strength than the brackets by American, Dentsply, and Ormco. The 3M brackets are followed by American and Ormco, which have a significantly higher resistance to fracture than the Dentsply brackets.

Since the sample size is relatively small for each manufacturer, we further applied Kruskal–Wallis to confirm if there are significant differences in the resistance of the tie wings to fracture among the manufacturers. The *P*-value from the test was <.0001, therefore the conclusion is the same as that from the ANOVA. Then the pairwise multiple comparison analysis was performed to find the difference among each pair of the manufacturers using the DSCF procedure (20). Using the DSCF method, Table 3 shows that each pair of the manufacturers are significantly different in resistance with the *P*-value ranging from .0009 to .0037.

When the groups were compared to each other using a post hoc analysis with adjusted *P*-values of less than .0001 (using the Tukey method), they showed a significant difference in mean tensile strength at peak local maximum (MPa) with the exception being the American Radiance and Ormco Symetri brackets (Table 4).

DISCUSSION

Many different types of ceramic brackets are available on the market today from which an orthodontist can choose. As mentioned, there is an increased demand for esthetics in orthodontics at the present time.[1] When offering ceramic appliances as a

Table 1. Fracture resistance of the tested brackets

Group	No. Obs	Mean (MPa)	Std Dev (MPa)	Lower 95%, CL for Mean	Upper 95%, CL for Mean
3M Clarity	10	134.25	9.92	127.16	141.34
American Radiance	10	61.91	2.99	59.76	64.05
Ormco Symetri	10	57.69	7.25	52.50	62.88
Dentsply Ovation	10	30.63	1.69	29.43	31.84

CL, Confidence Level

Table 2. ANOVA analysis results

Source	DF	Sum of Squares	Mean Square	F	Pr > F
Model	3	58897.99805	19632.66602	482.55	<0.0001
Error	36	1464.65905	40.68497		
Corrected total	39	60362.65710			

DF, Degree of Freedom.

treatment modality, it is important to have a bracket that maintains its integrity and does not fracture. In doing so, the orthodontist saves cost, time, and the inconvenience of replacement to both the clinician and the patient. Bracket fracture also affects the ability of the bracket to effectively transfer orthodontic forces to the tooth which may affect overall treatment time. Tie wing fractures, bracket fractures, and debonded brackets all require replacement.[11,18] The primary aim of the present study was to determine if there were differences in the fracture resistance of the tie wings from 4 manufacturers' popular ceramic brackets.

This study was able to confirm that there are significant differences in the resistance of the tie wings to fracture among the manufacturers tested. This is similar to the results from the Johnson study which also confirmed that bracket tie wing fracture will vary from manufacturer to manufacturer.[2] As shown by the data in Table 1, the 3M Clarity brackets had the highest resistance to tie wing fracture followed by American Radiance Plus, Ormco Symetri, and lastly, Dentsply Ovation S. The data in Table 2 showed that American Radiance Plus and Ormco Symetri did not have a significant difference in their tie wing fracture resistance.

When evaluating tested polycrystalline versus monocrystalline brackets, we are not able to confirm that one manufacturing method has a higher resistance to fracture than another. Comparing the mean tensile strengths at peak maximum of all the polycrystalline brackets (3M Clarity, Ormco Symetri, and Dentsply Ovation S), one sees a large range in the reported averages with the monocrystalline bracket (American Radiance Plus) falling in the middle. When comparing and contrasting with the Johnson study, the researchers found that their single monocrystalline bracket could not be fractured prior to the steel ligature breaking which occurred at a mean MPa of 198.65, while the polycrystalline brackets were able to fracture.[2] In the current study, there was no steel ligature breakage prior to fracture of the tie wing despite using a smaller (0.012-inch vs. 0.014-inch) steel ligature. A smaller ligature was chosen to provide more engagement of the tie-wing due to the depth of the tie-wing undercut. As previously mentioned, it is suggested that the differences in manufacturing processes result in disparities in strength with monocrystalline being stronger than polycrystalline.[2,13,14] If we assess our data with the elimination of the polycrystalline "outlier" (3M Clarity), then we do see that the monocrystalline (American Radiance Plus) was stronger than the remaining polycrystalline brackets. However, as mentioned, the American Radiance Plus and the Ormco Symetri did not have statistically significant differences. A further study could be performed with more groups of each type of manufacturing process to determine if one process is stronger than the other.

Another factor that has been reported to facilitate fracture of ceramic brackets is scratches on the surface of the ceramic that seem to impact the tensile strength characteristics of the ceramic.[21,22] Even small scratches have been reported to reduce the force needed for fracture. To avoid this impact on the current study, extreme care was taken to avoid scratching the surface of the brackets when mounting samples or engaging ligature wire. If scratches to the ceramic surface leads to fracture, orthodontists need to take care in their practice to avoid scratching the ceramic surface when tying in archwires. Consideration should be given to using elastic ligatures or coated ligatures for archwire ligation which may reduce the frequency of ceramic bracket fracture.

Care was taken to maintain the most standardization possible throughout the entire process which included the orientation and mounting of the brackets in the same manner (to the stainless steel washers and in the Instron machine), usage of new ligature wires for each group, and calibration of the Instron

Table 3. Dwass, steel, Critchlow-Fligner method for pairwise 2-sided multiple comparison analysis

Group	Wilcoxon Z	DSCF Value	Pr > DSCF
Dentsply Ovation vs. American Radiance	−3.7811	5.3472	0.0009
Dentsply Ovation vs. Ormco Symetri	−3.7811	5.3472	0.0009
Dentsply Ovation vs. 3M Clarity	−3.7811	5.3472	0.0009
American Radiance vs. Ormco Symetri	3.7796	5.3452	0.0009
American Radiance vs. 3M Clarity	3.4017	4.8107	0.0037
Ormco Symetri vs. 3M Clarity	−3.4773	4.9176	0.0028

Table 4. Post hoc Tukey's test

Adjusted *P*	3M Clarity	American Radiance	Dentsply Ovation	Ormco Symetri
3M Clarity	_______	<0.0001	<0.0001	<0.0001
American Radiance	_______	_______	<0.0001	0.3562
Dentsply Ovation	_______	_______	_______	<0.0001
Ormco Symetri	_______	_______	_______	_______

equipment. However, operator error could be a limitation to this study. Variations during the manufacturing process of the brackets may be a limitation, as well. Further research with more groups and larger sample sizes could further validate the information. An alternative study that mimics clinical tie wing fracture, similar to intraoral forces while eating, could be beneficial.

In summary, it does appear to be wise to choose a bracket with the highest resistance to tie wing fracture to combat the issue of ceramic brackets breaking and needing to be replaced throughout orthodontic treatment.

CONCLUSION

3M Clarity brackets had the highest resistance to tie wing fracture. Dentsply Ovation S had the lowest resistance to tie wing fracture. Ormco Symetri and American Radiance did not have statistically different resistances to tie-wing fracture.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Louisiana State University Health Sciences Center, (Approval No: 19024).

Informed Consent: N/A.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - M.J., Q.Y., P.A., R.B.; Design - M.J., X.X., P.A., R.B.; Supervision - H.M., X.X.; Funding - M.J.; Materials - M.J., X.X.; Data Collection and/or Processing - M.J., H.M., A.B.; Analysis and/or Interpretation - Q.Y.,M.J.; Literature Review - M.J.; Writing - M.J.; Critical Review - Q.Y., A.B., X.X., H.M., P.A., R.B.

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

Funding: The authors declared that this study has received no financial support.

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TURKISH JOURNAL of ORTHODONTICS

DOI: 10.5152/TurkJOrthod.2022.20008

Original Article

Changes in Color Stability and Surface Roughness of Teflon-Coated Arch Wires After Clinical Use

Betül Kula[1], Berza Yılmaz[2], Elif Karaaslan[3]

[1]Department of Orthodontics, İstanbul Galata University, Faculty of Dentistry, İstanbul, Turkey
[2]Department of Orthodontics, Bezmialem Vakıf University, Faculty of Dentistry, İstanbul, Turkey
[3]Department of Medical Microbiology, Bezmialem Vakıf University, School of Medicine, İstanbul, Turkey

Cite this article as: Kula B, Yılmaz B, Karaaslan E. Changes in color stability and surface roughness of teflon-coated arch wires after clinical use. *Turk J Orthod.* 2022;35(4):260-267.

Main Points

- Esthetic wires cannot maintain their surface integrity after clinical use.
- Coating materials should be strengthened.
- The core material of the esthetic arch wires can be enhanced to make antibacterial release.

ABSTRACT

Objective: Peeling of polytetrafluoroethylene (Teflon)-coated esthetic arch wires results in rough surfaces that may cause plaque accumulation, and the exposed core material may not meet the esthetic expectations of patients. The aim of this study was to evaluate the in-vivo surface roughness, *Streptococcus mutans* colonization, and color stability of Teflon-coated arch wires from 3 different manufacturers.

Methods: Surface roughness and color data of 0.016-inch and 0.016 × 0.022-inch Teflon-coated arch wires from 3 different manufacturers were recorded as they were received (T0) and after 28 days of clinical exposure (retrieved) (T1) using an atomic force microscope and a spectrophotometer. The amount of *S. mutans* was assessed in terms of colony-forming units on the as-received and retrieved wires.

Results: The surface roughness increased significantly, and a clinically noticeable color change was observed in all groups after clinical use ($P < .005$). There was no statistically significant difference in the amount of *S. mutans* adhesion for most of the wires. No significant correlation was found between the amount of *S. mutans* adhesion and the surface roughness.

Conclusion: All the arch wires showed increased surface roughness and clinically noticeable color change. The surface roughness values were not found to be correlated with the amount of *S. mutans* adhesion.

Keywords: Color change, esthetic orthodontic arch wire, surface roughness, Teflon-coated arch wire

INTRODUCTION

The lack of esthetic appearance of orthodontic appliances is one of the greatest concerns for orthodontic patients. Different approaches such as the lingual orthodontic technique, clear aligners, or esthetic brackets have been introduced to satisfy esthetic expectations. Esthetic brackets are often used in combination with esthetic arch wires coated with Teflon. However, peeling of the coating material over time results in rough surfaces that are suitable sites for plaque accumulation. Moreover, it has been reported that the surface roughness of esthetic arch wires may reduce the performance of sliding mechanics and mechanical strength, since the exposed core material increases friction coefficient.[1]

Esthetic orthodontic arch wires are available in 2 forms: coated metal wires and nonmetal transparent wires. Epoxy resin, polytetrafluoroethylene (PTFE) (Teflon), parylene (silver polymer), rhodium, and, less frequently,

Corresponding author: Betül Kula, e-mail: betul_akyildiz@hotmail.com

Received: September 24, 2021
Accepted: February 20, 2022
Publication Date: December 30, 2022

palladium are the materials used in the coating of arch wires. Physical properties of coated arch wires vary depending on the thickness of the coating and the manufacturing process.[1-3]

PTFE is a commonly used material for esthetic coating and is known under the name Teflon® from DuPont Co. Teflon is a synthetic polymer consisting of carbon and fluorine. Because of the strength of carbon-fluorine bonds, Teflon is nonreactive, heat resistant, and hydrophobic. In the field of orthodontics, it is known as an anti-adherent and esthetic material with excellent mechanical properties, as well as good mechanical stability.[4-6]

In the literature, the optical, biological, and mechanical properties of esthetic arch wires such as sliding properties, coating stability, force transmission values, color stability, and plaque accumulation have been previously evaluated.[1,7-13] Many of these properties have been reported to be far from the ideals.

Despite their widespread use, in-vivo studies about changes in the surface of PTFE materials are not available in the literature. In addition, color stability has not been investigated in-vivo until today. The aim of this study was to evaluate the surface roughness, microbial plaque retention, and discoloration of Teflon-coated arch wires from 3 different manufacturers.

METHODS

This study was approved by the Ethics Committee of Bezmialem Vakıf University with the decision number 71306642-050.01.04. An informed consent form was signed by all the patients/parents involved in the study. The study was conducted on patients who presented to the Orthodontics Department of Bezmialem Vakıf University for fixed treatment.

The physical and microbiological characteristics of 0.016-inch and 0.016 × 0.022-inch Teflon-coated arch wires of 3 different manufacturers (EverWhite (EW) (American Orthodontics, Sheboygan, USA), Titanol Cosmetic (TC) (Forestadent, Pforzheim, Germany), Proflex (PF) (G&H Orthodontics, Franklin, USA)) were evaluated.

G*Power program was used for power analysis. A sample size calculation based on a pilot study showed that at least 9 specimens per group would be necessary to evaluate the surface roughness (d (effect size): 0.640, SD: 2.7, power: 0.39, and $\alpha = 0.05$) and *Streptococcus mutans* adhesion (d (effect size): 0.638, SD: 0.02, power: 0.39, and $\alpha = 0.05$) and minimum 2 specimens would be required to evaluate the color change (d (effect size): 19.687, SD: 0.13, power: 0.39, and $\alpha = 0.05$). Thus 15 patients were included in each group for possible data loss. Patients with good oral hygiene, no periodontal disease, permanent dentition, no caries, no systemic disease, no antibiotics used, no more than 3 mm of crowding, and who were not smoking were included in the study. All patients were given oral hygiene training by the same researcher, and a standard toothbrush and toothpaste were provided for free.

The arch wires were ligated with elastomeric ligatures (Pearl-colored ligatures, American Orthodontics, Sheboygan, USA) to 0.018-inch ceramic brackets (Clarity™ ADVANCED Ceramic Brackets; 3M, USA) for anterior teeth and to metallic brackets (Master Brackets; American Orthodontics, Sheboygan, USA) for posterior teeth. Surface roughness and color change data were collected initially (as-received) (T0) and after 28 days of clinical exposure (retrieved) (T1) (Figure 1). One wire was measured for each brand in the control group to assess surface roughness and *S. mutans* adhesion.

Figure 1. a, b. Intraoral (a) and extraoral (b) images of esthetic arch wires after clinical usage

An atomic force microscope (AFM) (NT-MDT, Netweaver Solaris, Moscow, Russia) was used in the semi-contact mode to analyze the surface roughness of the as-received and retrieved wire samples. The samples were prepared by cutting 5-mm pieces from one side and the non-curved flat ends of each arch wire. The AFM probe (NT-MDT-NSG01) (curvature radius, 10 nm) with a constant force of 1.45–15.1 N/m was applied on the samples that were fixed to a metal holder. Three surfaces were scanned in 2-mm intervals for each sample with a scanning area of 20 × 20 µm, and the mean surface roughness (Ra) was recorded. For the rectangular wires, measurements were taken from the 0.022-inch surface of the wires.

The *S. mutans* adhesion was investigated on the 15 pieces of each brand. Arch wire pieces of 20 mm in length were cut from the distal ends of the as-received and retrieved wires. The used arch wire pieces were kept in an ultrasonic cleaner for 10 minutes and in distilled water for 10 minutes before the experiment.[13] All the wires were sterilized in the autoclave at 121ºC for 15 minutes prior to the experiment.

Fresh cultures were prepared by streaking from −80ºC stocks and adding to 5% Sheep Blood Agar, followed by incubation at 37ºC with 5% CO_2 for *S. mutans* suspension. After 2–3 days of incubation, single colonies were selected, transferred to Brain Heart Infusion (BHI) broth, and incubated until the optical density of the culture reached 0.5 at 600 nm (Spectrophotometer, U-5100, HITACHI), which corresponds to 1.5×10^8 colony-forming units (cfu)/mL. Bacteria suspension was centrifuged and washed with phosphate-buffered saline (PBS), resuspended in the same

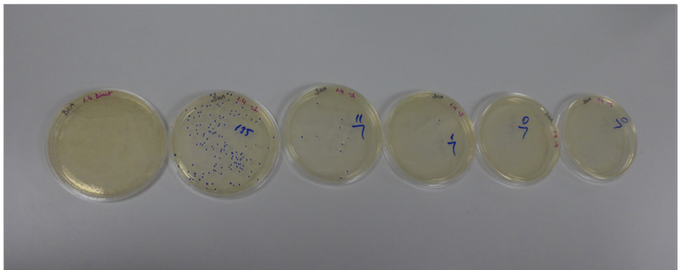

Figure 2. Bacterial colonies after 40 hours incubation of esthetic arch wires

initial volume of the fresh BHI broth. Each arch wire was placed in a 15-mL conical tube in aseptic conditions, and 2 mL of bacteria suspension was added to the tubes. All samples were incubated for 40 hours. One sample from each group was incubated with 2 mL of sterile BHI broth without bacteria for control. Also, Gram stain and Vitek MS analyses were performed with isolated colonies to confirm the purity of the culture. At the end of the incubation period, samples were transferred to a sterile 1.5-mL centrifuge tube and washed 3 times with PBS to remove planktonic bacteria. For enumeration of adherent bacteria, samples were sonicated (Bandelin, SONOPULS), vortexed, and serially diluted until 1:10 000 dilution was achieved. A 100 µL of sample from each dilution was inoculated to a BHI agar plate. Following an appropriate incubation period, colonies were counted, and the number of bacteria in each sample was calculated[9] (Figure 2).

Colorimetric measurements of samples with small dimensions such as arch wires are technically not possible with standard spectrophotometers. Moreover, round surfaces are known to be physically inappropriate for the color analysis. This is the reason why only rectangular arch wires were used for color measurements in a custom-made setting. Since the probe's sensor area is 5 mm wide, a total width of at least 3 mm was required to properly measure the color. Accordingly, in the present study, the setup was modified as described by Inami et al.[14] and 7-wire segments of each brand (11 mm in length, 0.016 × 0.022 inch) were tightly fixed using flowable resin (TetricEvoFlow Dental Flowable Composite, Ivoclar Vivadent, Saint Paul, NY, USA) from both edges.

The initial color of the unused wires was recorded using a VITA Easyshade Compact DEASYC220 (VITA Zahnfabrik, Bad Sackingen, Germany) spectrophotometer with a special tip, which allows repeated measurements in the exact center of the samples.

Then, 2 of the wires in the middle were made removable, and two 11-mm long pieces cut from the flat part of the used wires were seated in the chamber. In this way, the segments of the used wires were placed in the middle of the setup, and 3 pieces of the unused wires were fixed on the right and left sides. The color was measured from the side of the wires facing the occlusal surface (Figure 3).

The color was measured before clinical exposure (T0) and after 28 days of clinical use (T1). The spectrophotometer was calibrated according to the manufacturer's instructions. Each measurement was repeated 3 times, and the mean value was recorded.

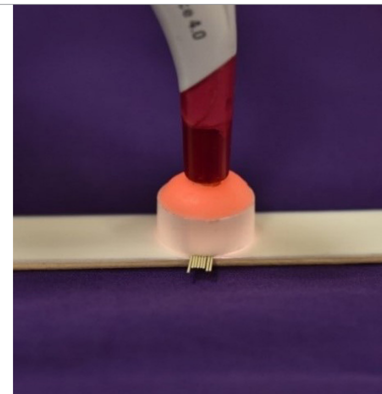

Figure 3. Color measurement of the arch wires

Color measurement was based on the CIE L*a*b* system. Δ*E* values were used to evaluate the color difference. ΔE values were converted to NBS (National Bureau Standards) values, which show clinically important definitions.[15]

Statistical Analysis

The data distribution was evaluated by using Kolmogorov-Smirnov and Shapiro Wilks tests. IBM SPSS for Windows (Version 22.0, IBM SPSS Corp., Armonk, NY, USA) was used for statistical analysis. The mean roughness and bacterial adhesion were compared using one-sample *t*-tests. The effect of coating and wire size on surface roughness and *S. mutans* adhesion were evaluated with the two-way ANOVA test, and the Tukey HSD test was used in post hoc analyses. One-sample *t*-test was used to evaluate the difference in surface roughness between as-received and retrieved wires. Student's *t*-test was used to evaluate the difference in *S. mutans* adhesion between as-received and retrieved wires. The change in continuous data was evaluated by using Pearson's correlation analyses. During the interpretation of the correlation coefficients, the values of 0.0–0.24, 0.25–0.49, 0.50–0.74, and 0.75–1.00 were considered weak, medium, strong, and very strong, respectively. Differences were considered statistically significant when $P < .05$.

RESULTS

Mean Surface Roughness and Biofilm Adhesion

Comparison of the mean surface roughness values (Ra) of the as-received and retrieved wire samples are shown in Table 1. In all groups, the mean surface roughness values were statistically and significantly higher than the initial values. Three-dimensional images of a wire sample before and after clinical use are presented in Figure 4.

The comparison of the surface roughness of the wires based on their manufacturers, based on their dimensions, and the intergroup comparison of the wires having the same brand and the same dimensions are shown in Table 2. Wire dimensions showed to have a statistically significant effect on the surface roughness ($P = .038$; $P < .05$). A detailed comparison of surface roughness for retrieved arch wires based on wire dimensions and manufacturer are shown in Table 3. In this detailed analysis, although there was a statistical difference between round and rectangular

Table 1. Comparison of the surface roughness means of as-received and retrieved arch wires (μm)

	0.016 PF (n = 15)	0.016 × 0.022 PF (n = 15)	0.016 TC (n = 15)	0.016 × 0.022 TC (n = 15)	0.016 EW (n = 15)	0.016 × 0.022 EW (n = 15)
Retrieved (Mean ± SD)	82.03 ± 32.31	107.85 ± 27.68	98.09 ± 27.43	113.27 ± 31.34	100.99 ± 23.89	102.32 ± 16.30
As-received	44.34	25.55	42.00	77.89	9.38	24.98
*P**	.003*	.000*	.000*	.004*	.000*	.000*

PF, Proflex; TC, Titanol Cosmetic; EW, EverWhite.
One-sample t-test, **P* < .05.

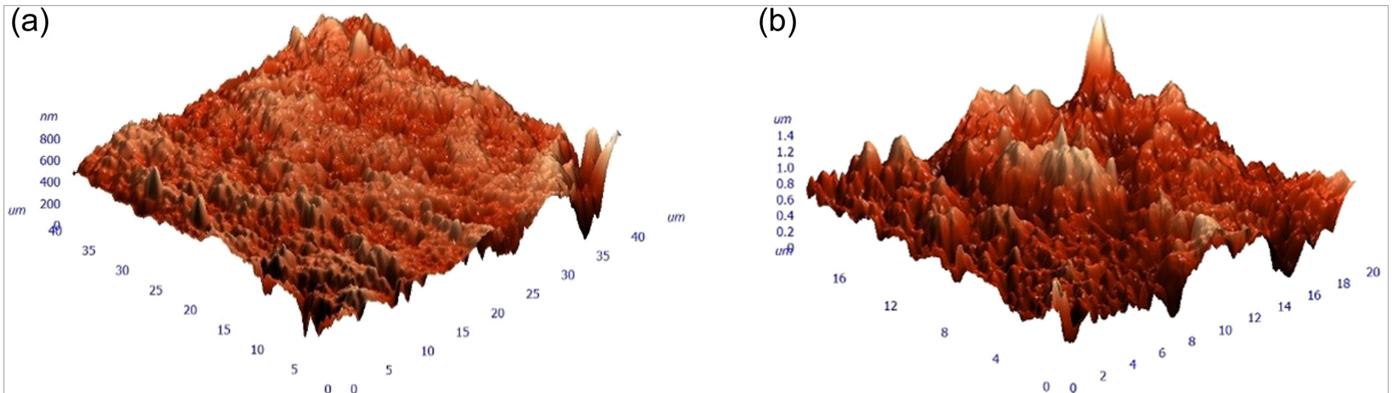

Figure 4. a, b. Atomic force microscopic three-dimensional images before (a, 40 × 40 μm) and after 4 weeks (b, 20 × 20 μm) of clinical usage

PF wires, no significant difference was observed between the other samples (*P* = .035; *P* < .05).

Statistical comparison of *S. mutans* adhesion in the as-received and retrieved arch wires are shown in Table 4. Two brands (PF and TC) showed significant changes after clinical use. *S. mutans* adhesion of rectangular PF wires was weaker after clinical use (*P* = .040; *P* < .05), while the amount of *S. mutans* bacterial adhesion of round TC wires was stronger after clinical use (*P* = .005; *P* < .05). The comparison of *S. mutans* adhesion for retrieved arch wires based on wire dimensions and manufacturer is shown in Table 5. A statistically significant difference was found in *S. mutans* bacterial adhesion of different-branded wires (*P* = .000; *P* < .05). The detailed comparison of the *S. mutans* adhesion based on the manufacturer and the wire dimension is shown in Table 6. No statistically significant difference was found in *S. mutans* adhesion for both round and rectangular wires (PF: *P* = .578; *P* > .05) (TC: *P* = .636; *P* > .05) (EW: *P* = .302; *P* > .05).

The difference between the brands in terms of mean *S. mutans* adhesion was statistically significant for the round (*P* = .002; *P* < .05) and rectangular wires (*P* = .048; *P* < .05) (Table 6). In the post hoc Tukey HSD analysis, a significant difference was noted between the round and rectangular PF and EW wires. The EW showed significantly higher bacterial adhesion compared to PF wires.

Table 2. Comparison of the surface roughness means based on the manufacturer and the wire dimension (μm)

Source	Type III Sum of Squares	df	Mean Square	F	*P*
Manufacturer	1294.193	2	647.097	0.886	.417
Wire Dimension	3285.43	1	3285.43	4.500	.038*
Manufacturer × Wire Dimension	1658.32	2	829.16	1.136	.328

Two-way ANOVA test, **P* < .05.

Pearson correlation analysis was performed to evaluate whether there was a linear relationship between the mean surface roughness and *S. mutans* adhesion in the arch wires after clinical use (Table 7). No significant correlation was found between the mean surface roughness and *S. mutans* adhesion.

Color Change

Δ*E* values were calculated at T0 and T1 (Table 8). No statistically significant difference was found between the color measurement values of the rectangular wires of each of the 3 brands at T1 (*P* = .203). To determine the clinical significance of the color change, Δ*E* values were transformed to NBS units (Table 9).

Table 3. Comparison of surface roughness for retrieved arch wires based on wire dimensions and manufacturer (μm)

	Wire Dimensions		
	0.016	0.016 × 0.022	
Manufacturer	Mean ± SD	Mean ± SD	*P*
PF	82.03 ± 32.31	107.85 ± 27.68	.035*
TC	98.09 ± 27.43	113.27 ± 31.34	.241
EW	100.99 ± 23.89	102.32 ± 16.3	.880
P	0.250	0.617	

PF, Proflex; TC, Titanol Cosmetic; EW, EverWhite; SD, standard deviation.
Two-way ANOVA test, **P* < .05.

Table 4. Comparison of the *Streptococcus mutans* bacterial colony-forming unit values of as-received and retrieved arch wires (log10) (cfu/mL)

	0.016 PF (Mean ± SD)	0.016 × 0.022 PF (Mean ± SD)	0.016 TC (Mean ± SD)	0.016 × 0.022 TC (Mean ± SD)	0.016 EW (Mean ± SD)	0.016 × 0.022 EW (Mean ± SD)
Retrieved arch wires	3.77 ± 0.44	3.89 ± 0.52	4.03 ± 0.52	4.13 ± 0.5	4.46 ± 0.19	4.36 ± 0.23
As-received arch wires	3.93 ± 0.50	4.52 ± 0.51	3.45 ± 0.16	4.14 ± 0.40	4.35 ± 0.42	4.35 ± 0.42
P	.529	.040*	.005*	.969	.458	.941

PF, Proflex; TC, Titanol Cosmetic; EW, EverWhite.
Student's t-test, **P* < .05.

According to the NBS values, a clinically noticeable color change was observed in the TC and EW wires. On the other hand, the PF wires showed a very significant color change. According to the clinical color matching reported by O'Brien,[16] the Δ*E* values obtained in all groups in this study can be classified as clinically noticeable.

DISCUSSION

Orthodontic arch wires are coated with the PTFE material for esthetic purposes. There are studies showing that this material reduces bacterial adhesion, but there are also studies defending just the opposite.[17-19] Moreover, a controversial condition is that the surface of the coating material can be roughened over time and cannot maintain its surface integrity because of high mechanical forces resulting from oral functions.[20] Water, which is known as a plasticizer in the saliva, affect resistance to sliding in aesthetic orthodontic wires coated with Teflon.[21] It has also been reported that proteins adhere quickly and irreversibly to roughened PTFE coatings.[22,23] As a result, peeling and coloration of esthetic arch wires can result in failure to meet esthetic expectations of patients. Considering the studies in the literature, we can maintain that there is no consensus on the contribution of PTFE in biofilm formation on esthetic orthodontic arch wires. Most of the studies in this field have been carried out in-vitro, and the color stability of this commonly used material has not yet been investigated in-vivo.

In clinical practice, the same bracket type is not used for every patient, and patients present with different amounts of crowding. In this study, we took precautions aiming to standardize the factors affecting the amount of peeling of the arch wires. Standard bracket types were used for the patients participating in the study. The severity of crowding changes the insertion angle of the wire to the bracket slot, which may increase the amount of friction and consequently result in more peeled-off material. Moreover, plaque accumulation increases when crowding is severe because the maintenance of oral hygiene becomes harder. This is the reason why patients with mild crowding (less than 3 mm) were included in the study. Training on oral hygiene maintenance was offered to all the patients verbally by the same researcher, and a toothbrush and toothpaste kit was given for free.

Surface Roughness and Biofilm Adhesion

In the literature, various devices have been used to measure the surface roughness of arch wires such as surface profilometry,

Table 5. Comparison of the *Streptococcus mutans* adhesion based on the manufacturer and the wire dimension (log10) (cfu/mL)

Source	Type III Sum of Squares	df	Mean Square	F	*P*
Manufacturer	3.782	2	1.891	10.475	.000*
Wire size	0.029	1	0.029	0.162	.689
Manufacturer × wire size	0.157	2	0.078	0.434	.650

Two-way ANOVA test, **P* < .05.

Table 6. Comparison of *Streptococcus mutans* adhesion for retrieved arch wires based on wire dimensions and manufacturer (log10) (cfu/mL)

	Wire Dimensions		
	0.016	0.016 × 0.022	
Manufacturer	Mean ± SD	Mean ± SD	*P*
PF	3.77 ± 0.44[a]	3.89 ± 0.52[a]	.578
TC	4.03 ± 0.52[ab]	4.13 ± 0.50[ab]	.636
EW	4.46 ± 0.19[b]	4.36 ± 0.23[b]	.302
P	.002*	.048*	

PF, Proflex; TC, Titanol Cosmetic; EW, EverWhite.
Two-way ANOVA test; **P* < .05. Note: Different letters (a and b) in the columns show the difference between groups.

Table 7. Correlation between mean surface roughness and *Streptococcus mutans* adhesion

Groups		Mean Surface Roughness and *S. mutans* Adhesion
0.016 PF (n = 15)	r	−.021
	P	.952
0.016 × 0.022 PF (n = 15)	r	−.326
	P	.327
0.016 TC (n = 15)	r	.025
	P	.943
0.016 × 0.022 TC (n = 15)	r	−.471
	P	.144
0.016 EW (n = 15)	r	.150
	P	.659
0.016 × 0.022 EW (n = 15)	r	−.046
	P	.893

PF, Proflex; TC, Titanol Cosmetic; EW, EverWhite.
Pearson correlation test. This text denotes if there is a correlation relatinship between mean surface roughness and S. Mutans adhesion.

Table 8. Comparison of color change (Δ*E*) of rectangular arch wires

	0.016 × 0.022 PF (n = 15)					0.016 × 0.022 TC (n = 15)					0.016 × 0.022 EW (n = 15)					
	Mean	SD	Median	Min.	Max.	Mean	SD	Median	Min.	Max.	Mean	SD	Median	Min.	Max.	*P*
Δ*E*	9.56	0.92	9.25	8.04	10.79	5.78	8.62	2.93	1.24	31.33	6.35	2.54	5.20	4.64	12.08	.203

PF, Proflex; TC, Titanol Cosmetic; EW, EverWhite.
One-way ANOVA test, **P* < .005; ****P* < .001.

atomic force microscopy, and laser spectroscopy.[2,12,24] Bourauel et al.[24] reported that there were high similarities between all these 3 methods.[25] The AFM device has many advantages, such as providing quantitative values for the assessment of surface roughness, requiring no additional preparation processes, and providing high resolution in the production of 3D images. A major disadvantage is that the surface of a sample cannot be analyzed as a whole, because the scanning speed is slow and the scanning area is small. In the present study, to be able to make accurate measurements with the AFM's probe, the wire samples were prepared by cutting 5-mm long pieces from the straight distal ends of the arch wires, instead of the curved anterior parts. The samples were prepared by taking into consideration the areas where the surface coating remained intact. Nevertheless, AFM is considered to be a reliable technique for evaluating the surface quality of orthodontic arch wires.[26,27] Because of the mentioned disadvantages of AFMs, one might object to relying only on a single method to assume about the total surface topography of arch wires. The fact that surface roughness was measured from a small area where the surface coating kept its integrity was a major methodologic limitation in our study. This is, in fact, a limitation in any study evaluating the surface roughness of arch wires.

S. mutans adherence to orthodontic materials has been accepted as an important factor for the pathogenesis of enamel demineralization during orthodontic treatment.[28,29] Since *S. mutans* increase during orthodontic treatment and because it has high cryogenic activity, we decided to include *S. mutans* in our study.[30] Taha et al.[9] evaluated the *in vitro* biofilm formation on rectangular esthetic NiTi arch wires. After 4 and 8 weeks of clinical use, they evaluated surface roughness and *in vivo* biofilm formation on the wires. The authors reported the presence of a positive correlation between surface roughness and biofilm adhesion. Although Taha et al.[9] measured the surface roughness in a similar way, the wires were removed from the mouth and the number of bacteria was measured immediately after.[9] However, in the current study, the wires were sterilized and placed into a culture medium that was prepared by the researchers, and no correlation was found between the surface roughness and biofilm adhesion. The difference may be explained by the difference in methods and the brand of the wires tested in the studies. In addition, this study can be criticized for inter-patient oral microflora differences. In our study, standardized culture media were preferred since the specific oral bacteria counts can change from patient to patient. Moreover, one of the wires tested by Taha et al.[9] had only labial surface coating while the wires tested in our study had all surfaces coated with Teflon.[9]

Table 9. Conversion of Δ*E* to NBS values

Arch Wires	Δ*E* Values	NBS Values
0.016 × 0.022 PF (n = 15)	9.56 ± 0.92	8.79 ± 0.84
0.016 × 0.022 TC (n = 15)	5.78 ± 8.62	5.31 ± 7.9
0.016 × 0.022 EW (n = 15)	6.35 ± 2.54	5.84 ± 2.3
NBS unit = Δ*E* × 0.92		

NBS, National Bureau Standards.

Elayyan et al.[1] reported that the surface roughness of epoxy-coated NiTi arch wires increased after 33 days of clinical use. It was reported that 25% of the coating disappeared and the metallic surface was exposed.[1] In the current study, all the wires showed noticeable peeling after clinical use, but the amount of missing coating was not quantitatively evaluated. It was noticed that the core material was less exposed in the segments of the wires inserted to the brackets in all groups. The Ra parameter increased in all groups after clinical use in a way that would significantly affect the biofilm formation as described by Quirynen et al.[22] A previous study reported that the highest amount of coating lost was in EW arch wires.[31] In our study, after clinical use, the increase in Ra values was higher in the rectangular PF wires compared to that in the unused counterparts.

Previous studies have reported that small variations in surface roughness have no significant effect on bacterial adhesion. There are also factors such as free surface energy and physicochemical properties that affect bacterial adhesion on dental materials.[31] This study has reported results that are consistent with the results of our study; that is, no significant correlation was found between the surface roughness and bacterial adhesion in orthodontic materials.

There are differences in the surface roughness of coated wires among different brands. The chemical composition of the coating material and the production technique are the factors affecting the surface properties of orthodontic wires.[32] In our study, although the coating material was the same in all groups, the difference in surface roughness values before and after clinical use might be explained with production method differences that are not fully explained by the manufacturers. The cross-sectional dimension of the core metal may vary depending on the coating material to reach the final arch wire thickness. This is another factor that may explain the non-uniform peeling of arch wires coated with the same material.[33] The thickness of the coating material of the wires used in our study is unknown. The companies suggest that they produce standard cross-sectional arch wires; however, the thickness of the coating is not something disclosed.

Color Change

Da Silva et al.[34] conducted a study on esthetic arch wires after 21 days of clinical use and reported the shortness of the oral exposure period as a limitation of their study. Similar to the findings of da Silva et al.[34] none of the esthetic arch wires used in our study presented ideal features after 28 days of clinical use. The surface roughness values measured on the remaining coatings showed significant increases compared to the as-received counterparts. The number of clinical trials in the literature to which we can compare our findings remains insufficient.

The color change is one of the physical changes that occur in esthetic arch wires following clinical exposure. We used ΔE^* values to evaluate the perceptibility of the color differences referring to previous studies.[17,35] The NBS rating system provides absolute criteria by which the ΔE^* values can be converted into definitions with clinical significance.[15] ΔE values below 3.7 are not visually noticeable and are considered to be clinically acceptable.[36] Douglas et al.[37] reported that approximately 50% of dentists could detect a color difference of 2.6 ± 3 units. In our study, ΔE values were 5.78 for the TC wires, 6.35 for the EW wires, and 9.56 for the PF wires. High ΔE values show that significant color changes occurred in all the PTFE arch wire groups.

One of the limitations of our study is the fact that the patients had different eating and drinking habits. Some patients preferred softer food items, while others preferred harder food items that could have caused more peeling. In addition, the acidity of consumed foods or toothbrush trauma caused by the patients might have affected the coating material integrity. The patients were given standard toothpastes and toothbrushes to standardize the erosive silica concentration in the pastes. However, the hand pressure was not, and cannot be, a parameter that could be standardized. Different coloring properties of consumed foods and liquids may affect the color stability.

CONCLUSION

Statistically significant increases were recorded in the surface roughness values of the clinically used wires. A statistically significant difference was noted between the initial *S. mutans* bacterial adhesion amounts of the different brands of arch wires. According to NBS units, a clinically noticeable color change was observed in the TC and EW wires, while a significant color change was observed in the PF wires. There was no significant correlation between the mean surface roughness and microbiological measurement values.

In the light of these findings, further clinical studies are required on factors affecting the integrity of coating material of esthetic arch wires. The physical features of the commercially available esthetic wires need to be ameliorated.

Ethics Committee Approval: Ethics committee approval was received from the Ethics Committee of Bezmialem Vakıf University (Approval number: 71306642-050.01.04).

Informed Consent: An informed consent form was signed by all the patients/parents involved in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – B.K.; Design – B.Y.; Supervision – B.Y.; Materials – B.K.; Data Collection and Processing – B.K., E.K.; Analysis and/or Interpretation – B.K.; Literature Review – B.K.; Writing – B.K.; Critical Review – B.Y.

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

Funding: The authors declared that this study has received no financial support.

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TURKISH JOURNAL of ORTHODONTICS

DOI: 10.5152/TurkJOrthod.2022.21136

Original Article

The Correlation Between Morphologic Characteristics of Condyle and Glenoid Fossa with Different Sagittal Patterns of Jaw Assessed by Cone-Beam Computed Tomography

Navid Kariminasab[1], Zahra Dalili Kajan[2], Arefeh Hajian-Tilaki[3,4]

[1]Department of Orthodontics, Faculty of Dentistry, Guilan University of Medical Sciences, Rasht, Iran
[2]Dental Sciences Research Center, Department of Maxillofacial Radiology, Faculty of Dentistry, Guilan University of Medical Sciences, Rasht, Iran
[3]Oral Health Research Center, Health Research Institute, Babol University of Medical Science, Babol, Iran
[4]Department of Orthodontics, Faculty of Dentistry, Babol University of Medical Sciences, Babol, Iran

Cite this article as: Kariminasab N, Dalili Kajan Z, Hajian-Tilaki A. The correlation between morphologic characteristics of condyle and glenoid fossa with different sagittal patterns of jaw assessed by cone-beam computed tomography. *Turk J Orthod.* 2022;35(4):268-275.

Main Points

- Glenoid fossa depth and glenoid fossa width were significantly different between different sagittal skeletal groups.
- There was a significant difference between articular eminence inclination of different sagittal skeletal patterns of jaw.
- No significant difference was found between the three groups in terms of the condylar position related to the glenoid fossa.

ABSTRACT

Objective: This study aimed to determine the relationship between the morphologic characteristics of condyle and glenoid fossa in different sagittal skeletal patterns using cone-beam computed tomography.

Methods: In this cross-sectional study, the lateral cephalometric and cone-beam computed tomography images of 90 patients were evaluated. The patients were categorized into three equal groups of sagittal skeletal patterns, according to the ANB angle. The greatest anteroposterior and mediolateral diameters of the mandibular condyles, as well as the angle between the long axis of the mandibular condyles and the midsagittal plane, were measured on the axial view of cone-beam computed tomography images. The anterior joint space, superior joint space, posterior joint space, articular eminence inclination, depth of the glenoid fossa, and width of the glenoid fossa were also measured on the central sagittal slices. One-way analysis of variance (ANOVA), Tukey's post hoc test and chi-square test were performed.

Results: Patients with the skeletal Class III had a significantly higher articular eminence inclination, while Class II patients had a lower articular eminence inclination ($P = .001$). In Class III patients, the depth of the glenoid fossa was greater, and the width of the glenoid fossa was smaller than in the other groups ($P < .01$). The anterior and posterior joint space did not show any significant differences between the 3 groups.

Conclusion: There were significant differences in some morphological characteristics of the condyle and glenoid fossa in patients with different sagittal skeletal patterns; therefore, this relationship should be considered in the treatment of these patients.

Keywords: Mandibular condyle, glenoid cavity, temporomandibular joint, cone-beam computed tomography, sagittal skeletal pattern

INTRODUCTION

The temporomandibular joints (TMJ) connect the mandible to the skull through the condyle in the glenoid fossa against the articular eminence of the temporal bone.[1] The mandibular condyles, similar to other TMJ structures, are essential in creating a balanced occlusion and stomatognathic system.[2] Different factors, including age, gender, the pattern of facial growth, pathological and functional changes, and dental occlusion changes, can

Corresponding author: Arefeh Hajian-Tilaki, e-mail: dr.arefehajian@yahoo.com

Received: August 19, 2021
Accepted: February 25, 2022
Publication Date: December 30, 2022

affect the TMJ morphology and position.[2-4] As a result of these changes, the re-modeling of the TMJ surface occurs as an adaptive reaction.[5]

Articular eminence is a region of the temporal bone that forms the anterior limit of glenoid fossa and the condylar process slides on it during different movements of mandible.[6,7] The articular eminence inclination is an essential factor in the biomechanics of TMJ and varies among different people. It represents the path of condylar movements and the amount of disk rotation on the condyle.[7-9] Different imaging modalities, such as panoramic imaging, lateral TMJ radiography, computed tomography (CT), cone-beam computed tomography (CBCT), and magnetic resonance imaging (MRI), can be used for evaluating the TMJ morphology.[2,10-12]

The use of conventional radiography has some inherent limitations, such as superimpositions of the surrounding structures, which can cause difficulties in the precise visualization of the condyles.[2,13,14] Among different imaging techniques, CBCT has some advantages over traditional two-dimensional radiography. It has been shown that CBCT produces three-dimensional images with high resolution, without magnification or distortion, and provides an estimate of the quantity and quality of bones.[11,12] The shorter scan time, lower absorbed dose of patients, and lower costs in contrast to CT imaging are among the other advantages of CBCT.[10-14]

Based on previous studies, the glenoid fossa and condyle shape may differ in people with various types of malocclusions. The data from some investigations report a significant association between different skeletal pattern and morphologic characteristics of TMJ.[2,13,15-18] In contrast, some studies have shown that the craniofacial morphology does not influence the morphology and position of the condylar area.[14,19,20] Since a long facial pattern can influence the condylar rotation, a vertical facial pattern may be an effective factor in the condyle-glenoid fossa relationship.[10] To eliminate this effect, the investigation of patients with a normal vertical skeletal pattern should be considered.

It seems that the sagittal jaw discrepancies and the morphology of the condyle and glenoid fossa may be related; however, there is controversial information in this area. Therefore, the aim of the present study was to determine the relationship between the morphological characteristics of the condyle and glenoid fossa in the different sagittal skeletal patterns (Class I, Class II, and Class III) using CBCT.

METHODS

This cross-sectional study was performed on the lateral cephalometric and CBCT images of 90 orthodontic patients, which were extracted from their orthodontic records. The radiographic records were obtained before the beginning of the orthodontic treatment and were not specifically taken for our study. At a confidence level of 95% and power of 80%, the sample size was estimated at 30 patients per skeletal group for detection of a standardized effect size of 0.7 regarding the morphological characteristics of the condyle between the groups. Finally, 90 patients who underwent CBCT scan for their orthodontic reasons were recruited in this study. All CBCT scans which presented bilateral condyles were included in this study. The selected patients did not have a history of TMJ disorders, trauma, TMJ surgery, cleft lip or palate, or craniofacial syndromes. Written consent was obtained from patients regarding that their orthodontic records were going to be used for study purposes. This study was approved in the ethics committee of Guilan University of Medical Sciences (Approval ID: IR:GUMS. REC.1396.475).

The patients' information, including age, sex, and cephalometric and condylar measurements, was recorded in a designed form for data collection. All CBCT scans were acquired using a NewTom VG CBCT system (QR SRL Company, Verona, Italy), with a field of view of 15×15 cm and an exposure factor of 110 kVp at 10-20 mA and exposure time of 3-5 s. The CBCT images were viewed by an observer in a semi-dark room on 1600 × 1200 pixel resolution with 24 inch monitor (Dell Inc, Round Rock, Tex, USA) on a computer running the Windows 7 (Microsoft, Redmond, Wash, USA) system.

According to the maxillofacial radiologist's report, a standard protocol was used for image acquisition. The CBCT images were acquired while the patient was in the maximum dental intercuspation. The patient's head was held down until the Frankfort plane was parallel to the floor, and the midsagittal plane was perpendicular to the floor.

The lateral cephalograms were acquired in a Planmeca ProMax device (Helsinki, Finland). Since the CBCT images of the patients were not full size we needed the lateral cephalograms to classify the subjects according to their sagittal skeletal pattern. Based on the lateral cephalometric examinations and manual technique tracing, the selected patients were categorized into three sagittal skeletal groups (30 patients per group), according to the ANB angulation: Class I (ANB, 2-4°), Class II (ANB > 4°), and Class III (ANB<2°). Class II patients were also divided into two subgroups (Class II division 1 and Class II division 2), based on the inclination of maxillary incisors. The inclination and distance of the upper incisor from the NA line (U1-Na) were recorded in degree and millimeter. Also, the Bjork's sum (N-S-Ar, S-Ar-Go, and Ar-Go-Me), lower anterior face height, Jarabak index (ratio of the posterior facial height [S-Go] to the anterior facial height [N-Me]), and Y-axis angle were calculated to determine the vertical facial pattern after tracing the lateral cephalogram. To eliminate the effect of different vertical facial patterns on the sagittal skeletal classification and the condyle-glenoid fossa relationship, all patients with a normal vertical skeletal pattern were considered."

For each sample, the right and left condyles were assessed separately. In the axial view, images that had the widest mediolateral

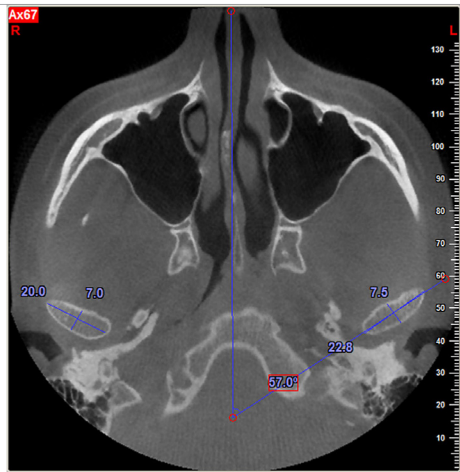

Figure 1. Linear measurement of the greatest anteroposterior and mediolateral diameter of the mandibular condyles and the angle between the long axis of the mandibular condyles and the midsagittal plane in axial view

diameter of the right and left condylar heads were selected (Figure 1). The following measurements were performed in the axial section: (1) the greatest anteroposterior diameter of the mandibular condyles; (2) the greatest mediolateral diameter of the mandibular condyles; and (3) the angle between the long axis of the mandibular condyles and the midsagittal plane. In the axial view, a line parallel to the long axis of the condyle was drawn (Figure 2A), so sagittal images were reconstructed with 2-mm thickness and interval (Figure 2B). Moreover, on the central sagittal images, the following measurements were obtained:

- Anterior joint space is defined as the shortest distance between the anterior wall of the glenoid fossa and the most anterior point of the condyle (Figure 3A).
- Superior joint space is defined as the shortest distance between the most superior point of the mandibular fossa and the most superior point of the condyle (Figure 3A).
- Posterior joint space is defined as the shortest distance between the posterior wall of the glenoid fossa and the most posterior point of the condyle (Figure 3A).
- Articular eminence inclination is defined as the angle between the true horizontal plane and the plane passing through the most inferior point at the crest of the articular eminence and the most superior point in the roof of the fossa (Figure 3B).
- Depth of the glenoid fossa is defined as the perpendicular distance between the highest point of the fossa and the line passing through the posterior glenoid process and the most inferior point of the articular eminence.
- Width of the glenoid fossa is defined as the distance between the posterior glenoid process and the most inferior point of the articular eminence.

The centric position of the condyles was evaluated by comparing the measurements of the anterior and posterior joint spaces in the right and left condyles. According to the formula proposed by Pullinger et al.[21] the condylar position was classified as anterior, concentric, and posterior:

Linear ratio= (P-A)/(P+A)×100.

The letters A and P indicate anterior and posterior joint spaces, respectively. If this ratio is less than -12%, the condylar position is considered posterior, if it is between -12% and +12% it is considered as concentric position, and if its more than +12% it is classified as anterior condylar position. The condylar position was evaluated by an examiner, who was blind to the patients' skeletal classification. All measurements were done by the same examiner after a two-week interval. The intra-observer reliability was above 0.85 for all measurements. The mean values of duplicate measurements were used for statistical analyses. Also, for the right and left sides, the mean values were measured separately.

Statistical Analysis

The statistical analysis was performed by using Statistical Package for the Social Science software version 23.0 (IBM SPSS Corp., Armonk, NY, USA). Descriptive statistics are presented as mean ± standard deviation (SD), according to the anterior-posterior skeletal relationships. The normal distribution of condylar measurements was examined by the Kolmogorov-Smirnov test,

Figure 2. A, B. Reconstruction of CBCT sections in a sample case. (a) Axial views in which the condylar process had its widest mediolateral diameter, (b) Central sagittal section of the condyle

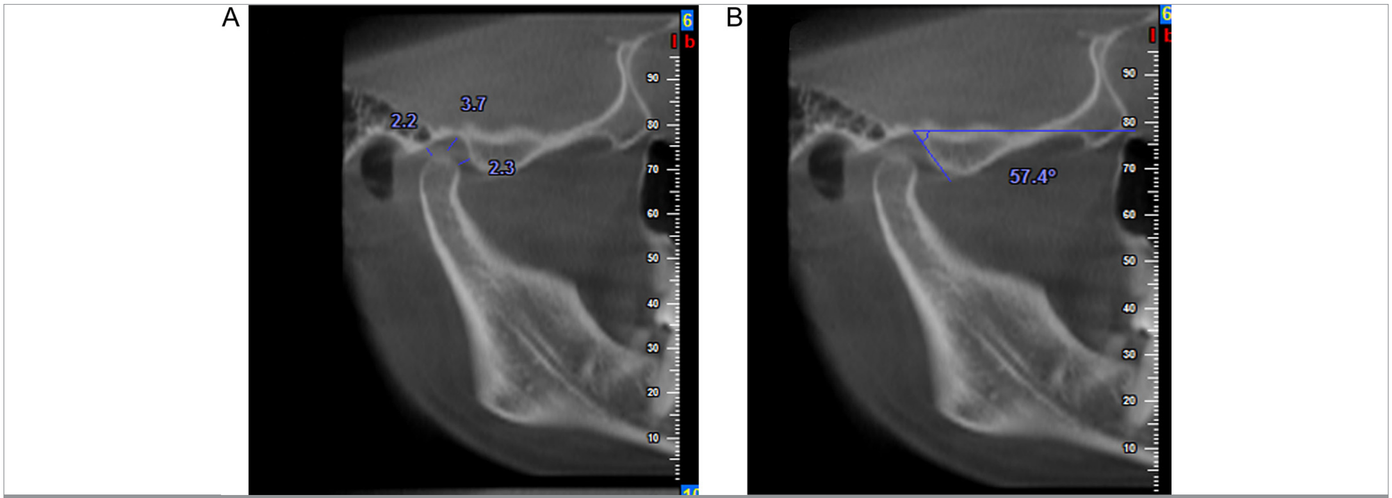

Figure 3. A, B. Linear measurement of anterior, superior, and posterior joint spaces (A) and articular eminence inclination (B) on a central sagittal view

and all variables satisfied the normality assumption. One-way ANOVA was performed to compare the mean condylar measurements in different skeletal relationships. Pairwise comparison between the groups was also performed using Tukey's post hoc test. A chi-square test was used to assess the association between the condylar position and craniofacial morphology. In addition, Pearson's correlation coefficient was measured to determine the correlations between the condylar measurements of the right and left sides. A P-value of less than 0.05 was considered significant in all tests.

RESULTS

The mean age (±SD) of the patients was 20.78 ± 4.72 years (range: 18-35 years). The study population comprised 41 (45.6%) males and 49 (54.4%) females. The descriptive characteristics, including sex and age, and other cephalometric features of Class I, Class II, and Class III malocclusions, are shown in Table 1. The mean Jarabak index and Bjork's sum were 64.02 ± 3.44 and 395.67 ± 3.80, respectively.

The mean values of the right and left condylar and glenoid fossa measurements are presented in Table 2. The mean articular eminence inclination on the right side was 49.59 ± 4.75°, 32.94 ± 7.60°, and 55.80 ± 2.97° in Class I, Class II, and Class III patients, respectively. On the other hand, the mean articular eminence inclination on the left side was 49.24 ± 4.80°, 33.32 ± 8.10°, and 55.69 ± 3.05° in Class I, Class II, and Class III patients, respectively. There was no significant difference in the articular eminence inclination between the right and left sides. The articular

Table 1. Descriptive statistic of study samples by skeletal pattern

Skeletal Pattern Variables		Class I (n = 30)	Class II (n = 30) Div I (n = 19)	Class II (n = 30) Div II (n = 11)	Class III (n = 30)
Sex (%)	Male	11 (36.7)	8 (42.1)	4 (36.4)	18 (60.0)
	Female	19 (63.3)	11 (57.9)	7 (63.6)	12 (40.0)
Age (years) Mean ± SD		19.1 ± 3.7	21.4 ± 6.5	20.2 ± 4.2	22.3 ± 4.0
SNA (°) Mean ± SD		79.9 ± 2.2	82.8 ± 3.6	82.5 ± 3.2	79.4 ± 3.7
SNB (°) Mean ± SD		76.9 ± 2.5	77.1 ± 3.4	77.0 ± 3.6	79.5 ± 3.7
ANB (°) Mean ± SD		3.1 ± 0.7	5.7 ± 1.7	6.4 ± 1.4	0.1 ± 1.2
U1–NA (°) Mean ± SD		19.7 ± 5.5	27.9 ± 8.3	8.4 ± 3.8	24.7 ± 5.2
U1-NA (mm) Mean ± SD		4.4 ± 1.3	6.7 ± 2.3	0.9 ± 1.8	5.7 ± 0.9
NSAr (°) Mean ± SD		125.5 ± 5.8	126.2 ± 4.5	124.4 ± 5.6	124.9 ± 4.4
SarGo (°) Mean ± SD		141.2 ± 6.9	141.2 ± 5.1	143.7 ± 6.5	142.9 ± 4.8
ArGoMe (°) Mean ± SD		128.9 ± 4.0	127.8 ± 4.6	126.0 ± 5.6	128.6 ± 5.6
Sum (°) Mean ± SD		395.7 ± 3.7	395.2 ± 4.1	394.1 ± 3.6	396.5 ± 3.8
Yaxis (°) Mean ± SD		59.4 ± 2.9	61.1 ± 4.6	59.8 ± 4.7	59.9 ± 3.0
LAFH (mm) Mean ± SD		60.7 ± 4.5	65.7 ± 6.4	61.3 ± 5.0	65.5 ± 5.6
Jarabak index (S-Go/N-Me) (%) Mean ± SD		62.7 ± 3.2	65.9 ± 4.3	65.1 ± 3.1	63.7 ± 2.5

SD, standard deviation; LAFH, lower anterior face height.

Table 2. Mean values of condylar and glenoid fossa measurements between 3 sagittal skeletal patterns in the tight and the left sides

Morphologic Characteristics		Skeletal Pattern: Class I (Mean ± SD)	Class II: Div1 (Mean ± SD)	Class II: Div2 (Mean ± SD)	Class III (Mean ± SD)	*P*
Articular eminence inclination (°)	R	49.59 ± 4.75	32.36 ± 8.17	33.94 ± 6.74	55.80 ± 2.97	.001
	L	49.24 ± 4.80	32.97 ± 8.74	33.93 ± 7.21	55.69 ± 3.05	.001
Glenoid fossa depth (mm)	R	6.36 ± 0.99	7.09 ± 1.40	6.55 ± 1.73	8.64 ± 4.58	.007
	L	6.46 ± 0.93	7.06 ± 1.14	6.63 ± 1.94	8.47 ± 4.30	.01
Glenoid fossa width (mm)	R)	17.05 ± 1.79	17.44 ± 2.61	17.64 ± 4.39	15.28 ± 3.56	.01
	L	16.96 ± 1.57	17.52 ± 2.46	17.25 ± 4.24	15.37 ± 3.47	.01
Anterior joint space (mm)	R	1.60 ± 0.72	1.67 ± 0.51	1.18 ± 0.68	1.65 ± 0.29	.09
	L	1.56 ± 0.73	1.51 ± 0.53	1.13 ± 0.60	1.49 ± 0.33	.2
Superior joint space (mm)	R	2.48 ± 0.51	3.23 ± 1.30	2.87 ± 0.84	2.68 ± 0.65	.02
	L	2.64 ± 0.52	2.79 ± 0.95	2.97 ± 0.91	2.56 ± 0.66	.37
Posterior joint space (mm)	R	1.73 ± 0.57	1.91 ± 0.78	1.97 ± 0.53	1.61 ± 0.49	.2
	L	1.71 ± 0.58	1.81 ± 0.71	1.89 ± 0.40	1.76 ± 0.53	.8
Anteroposterior diameter of condylar process (mm)	R	7.75 ± 0.95	8.54 ± 1.59	8.35 ± 1.74	7.47 ± 1.29	.01
	L	8.19 ± 1.41	8.49 ± 1.50	8.48 ± 1.30	7.69 ± 1.01	.06
Mediolateral diameter of condylar process (mm)	R	17.35 ± 3.12	18.83 ± 2.68	17.16 ± 2.87	18.51 ± 1.69	.2
	L	17.57 ± 2.73	18.69 ± 3.12	17.12 ± 3.02	17.96 ± 1.62	.7
Angle between condylar process/midsagittal plan (°)	R	69.32 ± 7.80	67.00 ± 6.63	65.71 ± 8.06	70.31 ± 4.17	.07
	L	68.95 ± 7.29	66.22 ± 7.34	64.65 ± 6.60	71.78 ± 4.1	.001

SD, standard deviation; R, right; L, left; *P*-values were calculated using the *F*-test in the analysis of variance.

eminence inclination was found to be the highest in Class III patients, followed by Class I and Class II, respectively.

The mean glenoid fossa depth on the right side was 6.36 ± 4.75°, 6.89 ± 1.58°, and 8.64 ± 4.58° in Class I, Class II, and Class III patients, respectively. The mean glenoid fossa depth on the left side was 6.46 ± 0.93°, 6.90 ± 1.54°, and 8.47 ± 4.30° in Class I, Class II, and Class III patients, respectively. The mean value of glenoid fossa width on the right side was 17.05 ± 1.79°, 17.51 ± 3.49°, and 15.28 ± 3.56° in Class I, Class II, and Class III patients, respectively. The mean glenoid fossa depth on the left side was 16.96 ± 1.57°, 17.42 ± 3.34°, and 15.37 ± 3.47° in Class I, Class II, and Class III patients, respectively. There was a significant difference in the glenoid fossa depth and glenoid fossa width between different sagittal skeletal groups ($P<0.05$). The depth of the glenoid fossa was significantly larger ($P=0.07$ in right side and $P=0.01$ in left side), and the width of the glenoid fossa was significantly smaller ($P=0.01$ in right and left side) on both sides in Class III patients, compared to the other groups. Also, the glenoid fossa depth was significantly higher in Class III patients, followed by Class II div. 1, Class II div. 2, and Class I. Nevertheless, the mean anteroposterior and mediolateral diameters of the condyles were not significantly different between the right and left sides ($P>.05$). The frequency of anterior, concentric, and posterior condylar positions on the right and left condylar sides in Class I, Class II, and Class III patients is presented in Table 3. No significant difference was found between the three groups in terms of the condylar position ($P=.40$ for right and $P=.08$ for left side). The *P*-values of Tukey's pairwise comparison between the groups were shown in Table 4.

DISCUSSION

In the current study, the morphological characteristics of the glenoid fossa and condylar eminence were assessed in 90 patients according to the sagittal skeletal relationships, using CBCT.

Table 3. Distribution of condylar position in each group

Skeletal Pattern	Anterior, n (%) R	Anterior, n (%) L	Concentric, n (%) R	Concentric, n (%) L	Posterior, n (%) R	Posterior, n (%) L	*P* R	*P* L
Class I	14 (46.7)	12 (40)	10 (33.3)	12 (40)	6 (20)	6 (20)		
Class II	16 (53.3)	15 (50)	10 (33.3)	12 (40)	4 (13.3)	3 (10)	.40	.08
Class III	7 (23.3)	7 (23.3)	17 (56.7)	22 (73.3)	6 (20)	1 (3.3)		

R, right; L, left; *P*-values were calculated by Chi-square test.

Table 4. Pairwise comparison of morphologic characteristics in different skeletal pattern

Morphologic characteristics	Skeletal pattern	Class I vs II	Class I vs III	Class II vs III
Articular eminence inclination (degree)	R	0.001	0.001	0.001
	L	0.001	0.001	0.001
Glenoid fossa depth (mm)	R	0.74	0.007	0.05
	L	0.79	0.01	0.06
Glenoid fossa width (mm)	R	0.81	0.06	0.01
	L	0.81	0.08	0.01
Anterior joint space (mm)	R	0.7	0.9	0.5
	L	0.4	0.8	0.7
Superior joint space (mm)	R	0.01	0.61	0.12
	L	0.48	0.90	0.25
Posterior joint space (mm)	R	0.41	1.00	0.43
	L	0.64	0.09	0.46
Anteroposterior diameter of condylar process(mm)	R	0.09	0.68	0.01
	L	0.63	0.31	0.05
Mediolateral diameter of condylar process (mm)	R	0.40	0.21	0.90
	L	0.69	0.82	0.97
Angle condylar process/ midsagittal Plan (degree)	R	0.22	0.83	0.07
	L	0.11	0.19	0.001

According to the findings, Class III patients had a significantly higher articular eminence inclination, while Class II patients had a lower articular eminence inclination. Also, Class III patients had a significantly higher glenoid fossa depth and a smaller glenoid fossa width.

Evaluation of the morphology of TMJ according to the sagittal skeletal relationships remains a challenge for clinicians.[10-14] Understanding the normal relationship of the condyle and the glenoid fossa can help clinicians identify the early onset of degenerative joint diseases, evaluate the established problems, and improve diagnosis and treatment plans for patients.[10,22] Different radiographic modalities, such as conventional radiography, conventional tomography, CT, MRI, and CBCT, have been proposed for evaluating the articular eminence inclination[23-28]; in the current study, CBCT was used.

Measurement of the articular eminence inclination varies in different studies.[6,8,9] It can be defined as the angle between the horizontal reference line (e.g., occlusal plane, palatal plane, Frankfort horizontal plane, and true horizontal plane) and the line that connects the highest point of the fossa and the most inferior point of the articular eminence. It can also be defined as the angle between the horizontal reference line and the best fit line drawn along the posterior slope of the articular eminence[6,8,9]; the first approach was used in the present investigation.

The articular eminence inclination can be evaluated in the most medial, central and most lateral slices, where the glenoid fossa and condyle are viewed. However, in the current study, for simplifying the assessment of our data, the articular eminence inclination was only examined in the central plane of the condyle, although the midpoint is preferable because it is the steepest part of the eminence.[8,29-31] According to a investigation by Katsavrias et al.[6] the articular eminence angle normally ranges from 30° to 60°. Articular eminence inclinations less than 30° and more than 60° were defined as flat and steep, respectively. Based on the outcomes of the present study, all of the patients were in the normal range of inclination. Although other factors, such as age, sex, dental occlusion, incisors, and canine guidance might affect variations of inclination in different skeletal patterns,[2] most of these variables were not considered in the present study.

Our results indicated that the glenoid fossa depth on the right and left sides was significantly higher in Class III patients, which is in accordance with the findings of studies conducted by Arieta-Miranda et al.[2] and Katsavrias et al.[16] On the other hand, the findings of a study by Krisjane et al.[13] demonstrated no significant difference between Class II and Class III patients. In the current study, the glenoid fossa width was considerably smaller in Class III patients. In contrast, Song et al.[32] evaluated TMJ in permanent dentition according to Angle's classification using CBCT and found that the width of the joint fossa was significantly larger in Class III patients. They also showed that the depth of the fossa was significantly smaller in Class III patients. This is in contrast to our findings. It should be mentioned that in their study the distance between the most inferior point of the articular eminence and the most inferior point of the external auditory meatus was defined as width of the glenoid fossa and the perpendicular distance between this line and the highest point of the fossa was defined as glenoid fossa depth which is different from the definition of glenoid fossa width and glenoid fossa depth in our study. Therefore conflicting results could be due to the variety in the external auditory meatus location in different sagittal skeletal classes.

In the axial slices, we assessed the symmetry of the condyles in the anteroposterior and mediolateral aspects. No considerable difference was observed in the condylar size between the three groups in the anteroposterior and mediolateral views. In a study by Rodrigus et al.[14] evaluating the TMJ parameters in Class II div 1 and Class III patients using CT, the mean anteroposterior and mediolateral diameters of the condyle were larger than our results.

According to several studies,[2,16,17,20,22] the condyles are positioned more anteriorly in Class II patients, while other studies have reported more posterior condyles in Class II patients.[33-34] In contrast, although most Class II patients had a more anteriorly positioned condyle in our study, the difference was not significant. Conflicting results in different communities may be attributed to the assessment method of the condylar position, ethnic background, and age range of the subjects. However, other factors, such as the radiographic modality and the method of assessing condylar position, may influence the outcomes, as well. A nonconcentric condyle-fossa relationship may be also associated with the abnormal function of TMJ.[13]

The present study was conducted on patients with a normal vertical skeletal pattern to eliminate the effect of a vertical relationship between the jaws. Based on some previous studies, the condylar position may be correlated with the vertical skeletal pattern.[3,35] In this regard, Paknahad and Shahidi[3] evaluated the association between condylar position and vertical skeletal craniofacial morphology. They suggested that patients with high-angle vertical patterns had more anteriorly positioned condyles, compared to those with low- and normal-angle vertical patterns; nonetheless, they did not find any significant difference between low- and normal-angle subjects. Lack of attention to this point in previous investigations might be the cause of conflicting results regarding relationship between the condylar position and morphological characteristics in different communities.[1,13,14] Also, the morphology of TMJ can alter significantly as patients grow older; this might be due to re-modelling and degenerative changes of the joint components.[18] Therefore, only young adult patients (age: 20.78 ± 4.72 years) were evaluated in this study.

This study had some limitations. First, measurement of the muscle activity, masticatory muscle load, and relation with dental occlusion was not possible; these factors could affect the morphology of the condyle-fossa relationship, especially the articular eminence inclination. Second, although we obtained the CBCT data from central sagittal slices for simplifying the process of data analysis, the condylar and glenoid fossa dimensions are different in different slices of the joint. Therefore, in the future studies it is recommended to also measure the most medial and the most lateral sections.

CONCLUSION

By using a CBCT-based method, we found that some morphological characteristics of the condyle and glenoid fossa were related to the sagittal skeletal relationships in an Iranian population. This correlation should be considered in the diagnosis of the temporomandibular joint pathologies, identifying the onset of a degenerative joint disease or diagnosis of an already established problem. Such information also allows the clinician to propose a better diagnosis and treatment plan, especially when the treatment involves orthognathic surgical approaches, as they can potentially lead to changes in the occlusal plan and condyle position. Therefore understanding the normal condylar position can help the clinicians in detecting the abnormal morphology and position of the temporomandibular joint.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Guilan University of Medical Sciences (Approval ID: IR:GUMS.REC.1396.475).

Informed Consent: Written informed consent was obtained from the patients.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – A.H.T., N.K., Z.D.K.; Design – A.H.T., N.K., Z.D.K.; Supervision – N.K., Z.D.K.; Materials – A.H.T., N.K., Z.D.K.; Data Collection and/or Processing – A.H.T.; Analysis and/or Interpretation – A.H.T.; Literature Review – A.H.T., N.K., Z.D.K.; Writing – A.H.T., N.K., Z.D.K.; Critical Review – A.H.T., N.K., Z.D.K.

Acknowledgments: The authors acknowledge the Deputy of Research and Technology of Guilan University of Medical Sciences for their support. We also would like to thank the staff of the radiology center for their assistance in collecting the radiographic files.

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

Funding: The authors declared that this study has received no financial support.

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TURKISH JOURNAL of ORTHODONTICS
DOI: 10.5152/TurkJOrthod.2022.21002

Original Article

20-Year Change in the Perception of Orthodontic Treatment: A Cross-Sectional Study

Mehmet Ali Yavan[1], Merve Nur Eğlenen[2]

[1]Department of Orthodontics, Adıyaman University, Faculty of Dentistry, Adıyaman, Turkey
[2]Department of Orthodontics, Yeditepe University, Faculty of Dentistry, İstanbul, Turkey

Cite this article as: Yavan ME, Eğlenen MN. 20-year change in the perception of orthodontic treatment: A cross-sectional study. *Turk J Orthod.* 2022;35(4):276-283.

Main Points

- The contributors' attitudes towards orthodontic treatment shifted from negative in the first decade to positive in the second decade.
- The frequency of entries containing procedure and motivation increased significantly and the frequency of entries containing complaint decreased significantly in the second decade.
- Pain was the most common complaint with a rate of almost 40% in both decades.
- The frequency of complaints regarding prolonged treatment increased in the second decade compared to the first decade.

ABSTRACT

Objective: To compare the changes in the perception towards orthodontics between the first and second decades over the 20-year period based on a collaborative hypertext dictionary site.

Methods: The orthodontics-related entries were searched on the EksiSozluk website (http://www.eksisozluk.com). The keyword was determined as "diş teli" ("brace") and a total of 1,028 entries that were contributed between 2001 and 2021 were analyzed. Entries were divided into five general categories based on their content: definition, asking for advice, humor, advertising, and transfer of experience. The transfer of experience category was further divided into four subcategories: procedure, motivation, advice, and complaint. For each entry, the attitude of the contributor was also noted. Entries were compared between the two decades with regard to content and attitude towards orthodontics.

Results: The average number of entries contributed per year was 13.40 ± 10.58 in the first decade and was 89.40 ± 44.67 in the second decade, the increase was statistically significant ($P < .05$). A significant difference was observed between the two decades in terms of content ($P < .05$). There was a proportional decrease in the definition and an increase in the transfer of experience. Moreover, the rate of entries containing a complaint decreased and motivation increased in the second decade ($P < .05$). On the other hand, there was also a significant change between the two decades with regard to the distribution of attitudes, whereby the rate of positive entries increased in the second decade ($P < .05$).

Conclusion: The contributors' attitudes towards orthodontics shifted from negative in the first decade to positive in the second decade.

Keywords: Orthodontics, collaborative hypertext dictionary, perception, social media

INTRODUCTION

Internet is the most widely used tool among today's information and communication technologies and it is known that the widespread use of the internet shapes life.[1–3] Today, people prefer the internet directly to access information, including health information, either by watching video sharing sites such as YouTube or reading the articles on the websites they access through search engines, or by reading the comments written by the contributors who share their knowledge and experience on a specific topic.[4] Due to the fact that websites are the primary source of information, the quality and reliability of information on websites has become more important

Corresponding author: Merve Nur Eglenen, e-mail: nureglenen@yahoo.com

Received: December 30, 2021
Accepted: March 22, 2022
Publication Date: December 30, 2022

than ever. On the other hand, online healthcare studies have started to be made and these studies are generally in the form of index studies and YouTube studies conducted on the quality and reliability of websites.[5–9]

With the advent of User-Generated Content, information sharing and circulation has become easier and freer than before, which in turn allows internet users to actively share everything they own and also to act directly as the source and commentator of the news stories.[10] Collaborative hypertext dictionary sites are those where people can define an object, person, or situation or comment on entries, share their experiences, and exchange ideas with people experienced in that field. As such, these sites are constantly updated with the addition of new comments. Additionally, these sites have an effective function in reflecting the perceptions and attitudes in the society to the public and they are mostly used by young people with a certain level of education. Therefore, they are important in terms of reflecting the perceptions and thoughts of a significant portion of the society.[10,11] One of the best known of these sites is EksiSozluk, which has received the highest number of monthly and total online definitions since its establishment in Turkey in 1999.[12] Moreover, EksiSozluk has had more than 10 times higher number of entries than that of its closest rival.[13] As defined by a sociologist "it is like Wikipedia, a social network and Reddit rolled into one."[14]

To our knowledge, although there have been various cross-sectional studies in the literature using collaborative hypertext dictionary sites for the evaluation of various topics such as perception of aging,[10] views regarding coronavirus 2019 disease (COVID-19) vaccine,[15] and perceptions regarding healthcare professionals,[16] there has been no study using collaborative hypertext dictionary sites in the field of dentistry or orthodontics to date.

The first entry about orthodontics in EksiSozluk was contributed in 2001. The aim of this study was to compare the changes in the perception of society towards orthodontic treatment between the first and second decades over the 20-year period between 2001 and 2021 based on the entries contributed to EksiSozluk related to orthodontic treatment. In addition, it was also aimed to reveal the problems related to orthodontic treatment and to increase the awareness among orthodontists on this issue and to identify possible solutions.

METHODS

The online comments written by EksiSozluk users on any topic, called entry, constituted the data of the present study. Since the data were collected from publicly available entries, no ethics committee approval was required.

The orthodontics-related entries were searched on the EksiSozluk website (http://www.eksisozluk.com) on August 1, 2021. The keyword to be used in the search was determined as "diş teli" (meaning "brace" in English) based on the statistics obtained from Google Trends (https://trends.google.com/trends/?geo=TR) regarding the searches performed in the field of orthodontics in Turkey since 2004. Over the last 20 years, only 136 entries were found in EksiSozluk including the keyword "orthodontics," which is the most searched keyword following "braces" in Google Trends. Only the keyword "brace" was chosen for the standardization of the researched entries.

All the 1,032 entries that were contributed between September 13, 2001, and August 1, 2021, were transferred to Microsoft SQL Server (Microsoft, Redmond, Wash, USA) and a total of 1028 entries were analyzed.

Age and gender of the authors were mostly anonymous in EksiSozluk; therefore, demographic analysis of entry contributors could not be performed. Entries that were unrelated to orthodontics and those containing insults and/or inappropriate language were not included in the analysis.

Since the entries mostly reflected the subjective opinions of the contributors and varied in type and length, they were not only examined with numerical values but also evaluated in terms of content and attitude.[15]

For the content analysis, the orthodontic appliances mentioned in the entries were divided into five categories:

1. Metal buccal brackets
2. Clear buccal brackets
3. Lingual brackets
4. Clear aligners
5. Removable appliances

To achieve standardization, entries that did not mention any device type were not included in this category.

For the general content, Initially, 100 randomly chosen entries were reviewed and then divided into 5 general categories based on their content:

1. Definition: This category involved entries that included a definition regardless of its source (i.e., scientific fact or personal opinion) (e.g., *orthodontic treatment allows split, crooked, protruding teeth to move to their original places*).
2. Asking for advice: This category included entries asking for the knowledge and experience of other contributors, such as those asking whether to wear braces, asking for information about orthodontists working in a certain location, and those inquiring about the costs of orthodontic treatments (e.g., *Is there anybody here whose teeth deteriorated after orthodontic treatment; if yes, could you tell us how you solved the problem?*).
3. Humor: An interesting aspect about EksiSozluk is that it is also a well-known for the entries containing humor. Such entries were included in this category (e.g., *Bro, I just wonder if it [the appliance] was silver or white gold.*).
4. Advertising: Although it is forbidden to advertise or publicize a person/company/object on EksiSozluk, entries that

mentioned or recommended a specific physician, though extremely rarely, were included in this category (e.g., *I recommend the Orthodontic clinic.*).

5. Transfer of experience: This was the largest category and included entries in which contributors shared their own experiences (e.g., *This piece of metal caused unbearable pain in the week the brackets were changed, upsetting me the whole day, urging me to want to remove all my teeth. Moreover, it was a reason for not being able to sleep, but after the removal of the brackets, you become a person with an adorable smile.*).

Transfer of experience was further divided into four subcategories:

I. Procedure: This category included the entries in which the contributors described their clinical condition and/or the procedure(s) they underwent without expressing their own personal opinions (e.g., *Process: The rubber bands installed after the second month started to hurt a lot. In the third month, thick wires were installed and the gaps between my teeth were closed completely.*).

II. Motivation: This category included entries that were contributed with the aim of encouraging patients to undergo orthodontic treatment, attempting to motivate and convince them that although there could be some difficulties at the beginning of the treatment, beautiful smiles can be obtained at the end of the treatment. (e.g., *Although it was difficult at the beginning, the appearance of my teeth at the end of the treatment was worth all these difficulties.*).

III. Advice: Entries containing detailed advice on oral hygiene, eating, drinking, and the use of retention device based on contributors' personal experience were included in this category (e.g., *There were minor irregularities after the treatment. It was my fault; 6-7 months after the wires came out, I stopped using the plate given to me. You shouldn't neglect it!*)

IV. Complaint: Entries that only mentioned complaints and did not contain any statement of motivation regarding orthodontic treatment were included in this category. (e.g., *I can describe it with a single word: pain.*)

The entries included in the "Complaint" category were further divided into the following subcategories and they were included in several categories if they contained more than one type of complaints:

- IV-1. Pain
- IV-2. Wound
- IV-3. Eating and swallowing problems
- IV-4. Physical appearance
- IV-5. Speech problems
- IV-6. Elastics
- IV-7. Prolonged treatment
- IV-8. Retention devices
- IV-9. Relapse
- IV-10. Discoloration
- IV-11. Nonspecific (e.g., *That's a real torture!*)

Entries containing contributors' attitudes towards orthodontic treatment were divided into three groups:

1. Positive: Entries containing motivational phrases or those containing advice and satisfaction related to the post-treatment period.
2. Negative: Entries containing complaints regarding the procedure and post-treatment dissatisfaction.
3. Neutral: Entries that did not contain any subjective evaluation or emotional expressions.

Statistical Analysis

Sample size was calculated using G*Power statistical software (version 3.0.10; Heinrich Heine University Düsseldorf, Düsseldorf, Germany). A post hoc power analysis showed the power of the study to be 0.98 according to a 58% reduction in the rate of negative entries between decades, from 43% in the first decade to 25% in the second decade and a 2-tailed alpha level of 0.05.

Intra- and inter-rater reliability of the variables were calculated using Cohen's Kappa test. A total of 200 randomly selected entries were re-evaluated separately by two researchers (M.A.Y. and M.N.E.) 15 days after the initial evaluation.

Statistical analyses were performed using SPSS for Windows version 22.0 (IBM Corp., Armonk, NY, USA). Descriptives were expressed as mean, standard deviation (SD), and frequencies (n). The normal distribution of continuous variables was assessed using the Shapiro–Wilk test and all the variables showed normal distribution. The numbers of entries contributed during the two decades were compared using independent-samples t-test. Categorical variables were compared between the two decades using the Chi-square test. A P value of <.05 was considered significant.

RESULTS

Inter- and intra-rater agreement rates were 0.930 and 1.00, respectively. Only 4 out of 1032 entries were excluded from the study since they contained insults and thus the remaining 1028 entries were included in the analysis.

Table 1 presents the descriptives and comparison of the entries contributed in both decades. The average number of entries contributed per year was 13.40 $\pm$ 10.58 in the first decade and was 89.40 $\pm$ 44.67 in the second decade and the increase was statistically significant ($P < .05$) (Figure 1).

Although there was no significant difference between the two decades with regard to the distribution of device types ($P > .05$), there was a significant difference in terms of content ($P < .01$). Of note, 17.2% of the entries included a definition in the first decade and this rate decreased to 7.8% in the second decade. In contrast, 76.9% of the entries included transfer of experience in the first decade, and this rate was found to be 81.5% in the second decade.

Among the subcategories of the experience group, the entries containing comments regarding procedure (8.7% vs. 14.5%) and motivation (18.4% vs. 38.4%) showed an increasing trend, while

Table 1. Descriptive statistics of the entries

		First Decade (n = 134)	Second Decade (n = 894)	*P*
Number of entries contributed per year (Mean ± SD)		13.40 ± 10.58	89.40 ± 44.67	.000 *** α
Device type	Buccal metal (n, %)	93 (93%)	642 (92.6%)	.498 β
	Buccal ceramic (n, %)	4 (4%)	29 (4.2%)	
	Lingual (n, %)	0 (0%)	3 (0.4%)	
	Clear aligner (n, %)	1 (1%)	15 (2.2%)	
	Removable (n, %)	2 (2%)	4 (0.6%)	
Content	Definition (n, %)	23 (17.2%)	70 (7.8%)	.001 ** β
	Asking for advice (n, %)	0 (0%)	51 (5.7%)	
	Humor (n, %)	7 (5.2%)	39 (4.4%)	
	Advertising (n, %)	1 (0.7%)	5 (0.6%)	
	Transfer of experience (n, %)	103 (76.9%)	729 (81.5%)	
Content of transfer of experience	Procedure (n, %)	9 (8.7%)	106 (14.5%)	.000 ***β
	Motivation (n, %)	19 (18.4%)	280 (38.4%)	
	Advice (n, %)	16 (15.5%)	112 (15.4%)	
	Complaint (n, %)	59 (57.3%)	231 (31.7%)	

αIndependent samples *t* test, βχ^2 test, ***P* < .01, ****P* < .001, SD, standard deviation.

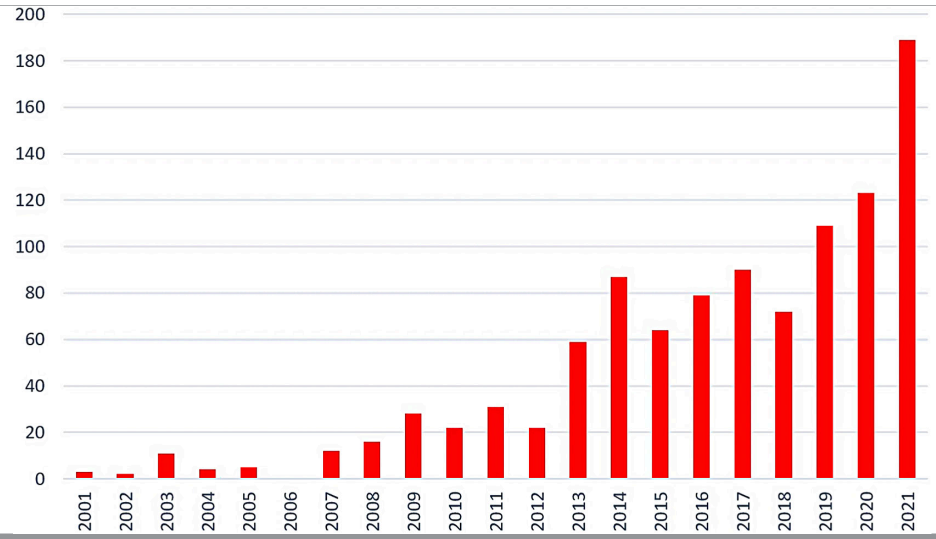

Figure 1. Distribution of entries by year

the entries containing comments regarding complaint (57.3% vs. 31.7%) showed a decreasing trend in the second decade compared to the first decade (*P* < .001).

Table 2 shows the distribution of complaints in both decades. The frequencies of subcategories including wound (18.64% vs. 12.12%), physical appearance (23.72% vs. 9.09%) and speech problems (18.64% vs. 3.03%) showed a decrease, whereas no change was observed in the complaints related to pain, eating and swallowing problems, elastics, retention devices, retention, and relapse. By contrast, the complaints related to prolonged treatment showed an increase (11.86% vs. 25.54%).

Table 3 presents the distribution of attitudes (positive, negative, and neutral) towards orthodontic treatment (Figure 2) in the entries containing comments related to device types and content. There was an overall significant difference between the two decades (*P* < .001). Of note, negative attitudes were more dominant in the first decade (43.3%), while positive attitudes were more dominant in the second decade (49.6%). Additionally, approximately one-quarter of the entries were neutral in both decades (25.4% and 25.2%, respectively). In terms of device type, however, there was a significant change in the frequency of attitudes in the entries related to metal buccal brackets between the two decades (*P* < .01), while no significant change was observed in the attitudes in the entries related to clear buccal brackets (*P* > .05). As for the content of the entries, no significant difference was found between the two decades with regard to the distribution of attitudes in the entries containing definition and humor (*P* > .05), while there was a significant increase in the positive attitudes in the entries containing transfer of experience in the second decade compared to the first decade (*P* < .01).

Table 2. Complaints mentioned in the entries

Complaint	First Decade (2001-2011)	Second Decade (2012-2021)
Pain (n, %)	23 (38.98%)	85 (36.79%)
Eating and swallowing problems (n, %)	18 (30.50%)	76 (32.90%)
Physical appearance (n, %)	14 (23.72)	21 (9.09%)
Wound (n, %)	11 (18.64%)	28 (12.12%)
Speech problems (n, %)	11 (18.64)	7 (3.03%)
Retention device (n, %)	8 (13.55%)	25 (10.82%)
Elastics (n, %)	7 (11.86%)	27 (11.68%)
Prolonged treatment (n, %)	7 (11.86%)	59 (25.54%)
Relapse (n, %)	4 (6.77%)	20 (8.65%)
Discoloration (n, %)	1 (1.69%)	7 (3.03%)
Nonspecific (n, %)	9 (15.25%)	40 (17.31%)

Table 3. Comparison of attitudes in different decades

		First Decade (2001-2011)			Second Decade (2012-2021)			
		Positive (n, %)	Negative (n, %)	Neutral (n, %)	Positive (n, %)	Negative (n, %)	Neutral (n, %)	P^{β}
Total		42 (31.3)	58 (43.3)	34 (25.4)	443 (49.6)	226 (25.3)	225 (25.2)	.000 ***
Device type	Buccal metal	33 (35.5%)	42 (45.2%)	18 (19.4%)	345 (53.7%)	189 (29.4%)	108 (16.8%)	.003 **
	Buccal ceramic	0 (0%)	3 (75%)	1 (25%)	16 (55.2%)	8 (22.6%)	5 (17.2%)	.110
Content	Definition	9 (39.1%)	2 (8.7%)	12 (52.2%)	34 (48.6%)	9 (12.9%)	27 (38.6%)	.509
	Humor	2 (28.6%)	3 (42.9%)	2 (28.6%)	10 (25.6%)	7 (17.9%)	22 (56.4%)	.313
	Experience	31 (30.1%)	53 (51.5%)	19 (18.4%)	397 (54.5%)	204 (28%)	128 (17.6%)	.000 ***

$^{\beta}\chi^2$ test, $^{**}P < .01$, $^{***}P < .001$.

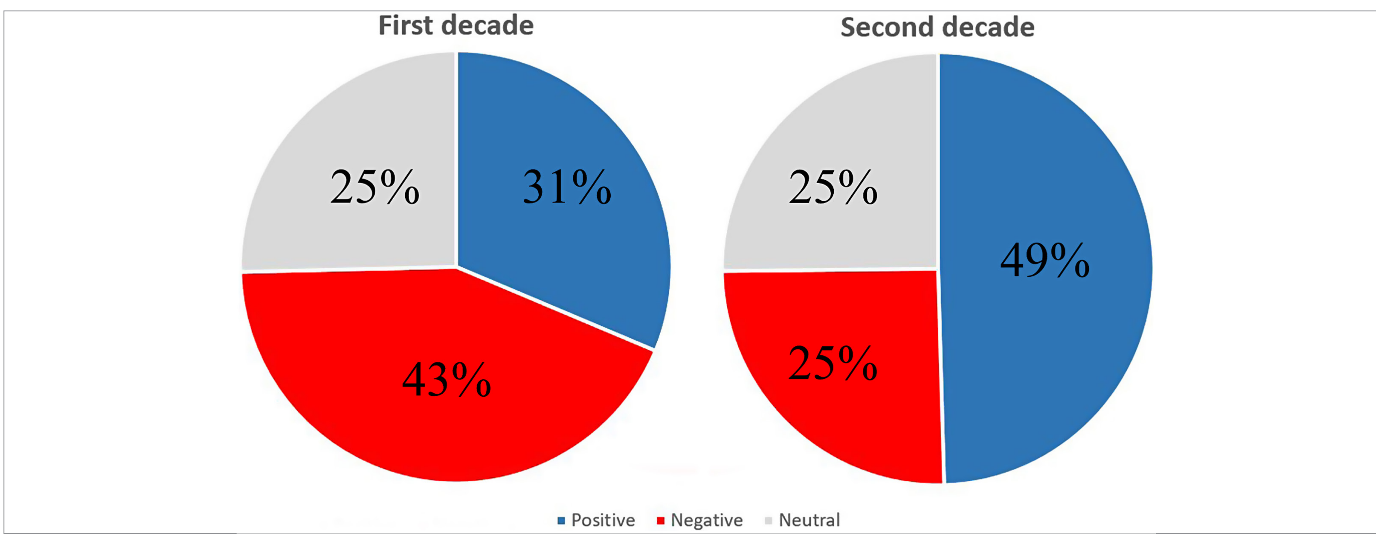

Figure 2. Schematic representation of attitudes toward orthodontic treatment in the entries of the last 2 decades

Table 4 presents the distribution of complaints about metal and clear buccal brackets. Among these complaints, pain (40%), eating and swallowing problems (34.50%), and prolonged treatment (24.31%) constituted the three most common complaints in buccal metal brackets, while pain (30.76%), discoloration (30.76%), and eating and swallowing problems (15.38%) constituted the three most common complaints in buccal clear brackets.

DISCUSSION

Social media provides an insight into current cultural and social trends of the society and into the modern understanding of beauty, particularly among patients undergoing orthodontic treatment.[17] The present study aimed to evaluate long-term attitudes based on the entries contributed to collaborative

Table 4. Complaints according to device type

Complaint	Buccal Metal	Buccal Ceramic
Pain (n, %)	102 (40%)	4 (30.76%)
Eating and swallowing problems (n, %)	37 (14.50%)	1 (7.69%)
Physical appearance (n, %)	88 (34.50%)	3 (23.07%)
Wound (n, %)	32 (12.54%)	1 (7.69%)
Speech problems (n, %)	14 (5.49%)	1 (7.69%)
Retention device (n, %)	34 (13.33%)	0 (0%)
Elastics (n, %)	62 (24.31%)	2 (15.38%)
Prolonged treatment (n, %)	31 (12.15%)	1 (7.69%)
Relapse (n, %)	21 (8.23%)	1 (7.69%)
Discoloration (n, %)	4 (1.56%)	4 (30.76%)
Nonspecific (n, %)	36 (14.11%)	2 (15.38%)

hypertext dictionary sites, which constitute an important branch of social media, regarding orthodontic treatment. In addition, by performing content analysis, it was aimed to determine the complaints of the contributors and to raise the awareness of orthodontists about these problems. Our research data consisted of the entries contributed to EksiSozluk, which is one of the most frequently visited collaborative hypertext dictionary sites with more than 700,000 active users who had a certain level of knowledge and ability to explain new communication technologies and the internet and who evaluated the phenomena from a different perspective.[16,18,19]

Our results indicated that the number of entries increased by almost 5 times in the second decade compared to the first decade. This finding could be explained by the rapid increase in the number of internet users and the growing interest in orthodontic treatment in the world within the last 20 years.[20,21]

Cross-sectional studies have shown that orthodontic patients are positively affected by the experiences shared by other patients on the internet.[22,23] This situation shows the importance of evaluating collaborative hypertext dictionary sites in terms of content. In our study, although there was no significant difference between the two decades with regard to device type, there was a significant increase in the number of entries about lingual brackets and clear aligners in the second decade, which implicates that the interest in these treatments will increase in the future. Jeremiah et al.[24] in line with our findings reported that the demand for lingual brackets and clear aligners have recently increased.

A significant difference was determined between the two decades with regard to the distribution of content types. Of note, entries containing a definition decreased while the entries containing transfer of experience increased in the second decade compared to the first decade. This finding indicates that the contributors did not need new definition entries and that they tended to share their experiences more frequently in the second decade. Moreover, this finding could be explained by the increasing number of individuals undergoing orthodontic treatment. Studies presenting similar findings to those of our study have shown that patients frequently share their experiences on social media platforms such as forums and blogs with people who receive orthodontic treatment like themselves and that it is easier for them to share their feelings in these environments rather than to communicate with their orthodontists.[23,25,26]

Evaluating social media content is essential for understanding the experiences, expectations, and motivational factors associated with orthodontic treatment.[17] Our findings showed a significant change in the subcategories of transfer of experience between the two decades, whereby the frequency of entries containing procedure and motivation increased significantly and the frequency of entries containing complaint decreased significantly in the second decade. These changes could be explained by the advancements in orthodontic technology, such as reduced bracket size, increased use of clear aligners, and increasing accessibility of lingual brackets and clear aligners.[27] Additionally, the increased frequency of entries regarding motivation could be attributed to the increase in the number of individuals receiving orthodontic treatment and in the number of people sharing their experiences on this topic in social life and on the internet and also could be associated with the reduction in the frequency of entries containing a complaint in the second decade.

In the entries analyzed, it was revealed that the attitudes towards orthodontic treatment shifted from negative in the first decade to positive in the second decade. In a similar way to our findings, Kim[28] reported that orthodontic treatment has gained increasing popularity in society and that the rate of positive perception among adults in their 20s had reached 63.2%. Similarly, Noll et al.[29] also reported that the attitude towards orthodontic treatment was mostly positive in their Twitter analysis. These findings could be associated with the increased acceptability of orthodontic appliances in line with the increase in aesthetic perception in society. Additionally, it could also be related to the increase in treatment options in line with the development of orthodontic appliances and the numerical increase in the number of patients undergoing orthodontic treatment.[24] Similarly, studies in the literature have shown that the cooperation of patients with orthodontic treatment increases and that they develop more positive attitudes towards the treatment in line with their increasing knowledge and experience regarding the treatment.[26] However, despite this positive change, approximately 30% of the entries analyzed in our study contained a complaint, which implicates that orthodontists should be more concerned about patients' complaints.

Patients are in active communication with other internet users, mainly to provide and receive support from each other and to share information.[17] Literature indicates that the experiences shared among patients often include problems such as poor oral hygiene, chewing problems, orthodontic pain, use of elastics, and difficulties in the use of retainers, while their posts related to motivation indicate that patients obtain excellent aesthetic outcomes and better occlusion at the end of the treatment.[23,25,26] In a Twitter study by Noll et al.[29] it was determined that the most common complaints of the patients were related to pain. Similarly, in our study, the pain was the most common complaint with a rate of almost 40% in both decades. Taken together, these findings implicate that orthodontist should inform their patients that pain is an expected outcome, which in turn could lead to beneficial outcomes in terms of long-term motivation since such preparation will increase patients' trust in the treatment and in the physician.

Common problems reported in the social media studies include eating and swallowing problems, difficult cleaning of brackets and archwires, soft tissue wounds, and the use of elastics.[17] Similarly, our findings indicated that one-third of the complaints reported by the contributors included eating and swallowing problems. Taken together, these findings suggest that orthodontists should inform patients regarding the likelihood of eating difficulties in treatments that involve appliances other than clear aligners and removable appliances, particularly in buccal brackets, and should prepare patients for this situation prior to the treatment.

Our findings showed that the frequency of complaints regarding prolonged treatment increased in the second decade compared to the first decade. Literature indicates that the duration of orthodontic treatment varies according to the type of malocclusion, treatment options, knowledge and experience of the orthodontist, patient's compliance with the treatment and follow-up sessions.[30] In addition, it is a common fact that if the duration of the treatment exceeds the time stated by the physician at the beginning of the treatment, this may cause dissatisfaction among the patients and thereby may lead to a complaint as a result of the perception of prolonged treatment.

In the second decade, a decrease was observed in the frequency of the complaints of intraoral wounds. The decrease observed in our study could be due to the advancements in bracket technology, such as reduction in bracket size, development of smoother bracket surfaces, elimination of traumas caused by ligature wires with the development of self-ligating brackets, and the reduction in the use of twisted wires.[31]

In our study, most of the complaints mentioned in the first decade were related to the physical appearance of brackets and braces. This finding could be due to the false impression of ugliness reflected by the main characters in TV series such as "Ugly Betty" and video clips such as Ketty Perry's "Last Friday Night," which were being screened on TV channels during the first decade and in which these characters were ugly individuals receiving orthodontic treatment.[32] Studies in the literature have shown that the acceptability of orthodontic appliances has increased due to the increase in dental and orthodontic awareness.[24] Similarly, in our study, the frequency of visual complaints showed a reduction in the second decade compared to the first decade. This finding could be associated with the aesthetic innovations in orthodontic appliances (e.g. mini brackets, clear brackets, custom brackets).[24]

Our findings, in a similar way to those of Twitter studies, indicated that one out of every 10 contributors complained about the use of elastics in both decades.[17] This finding suggests that patients should be informed about the difficulties of using elastics prior to the study.

Negative experiences with orthodontic retainers are frequently shared on Twitter, most of which include pain, speech problems, aesthetic anxiety, odor, and discoloration problems as well as difficulties experienced during the insertion and removal of these appliances during meals and their risk of loss.[17,29,33,34] Similarly, most of the entries analyzed in our study included complaints regarding retention devices. In addition, some contributors also complained of relapse caused by inadequate attention to the retention protocol. Accordingly, orthodontists should inform their patients about the risk of relapse after treatment and should also instruct them regarding the retention protocol.

In our study, the contents of complaints regarding metal buccal and clear buccal brackets were analyzed and the most interesting finding was the complaint of discoloration of teeth caused by devices or discoloration of clear elastic ligatures or brackets. Literature indicates that the color stability of aesthetic brackets can be affected by numerous factors such as their content, morphology, and surface properties.[35] Additionally, it has been shown that all plastic and ceramic aesthetic brackets can show discoloration due to endogenous and exogenous factors.[35] On the other hand, in order to obtain the desired aesthetic outcome, the bracket to be selected should be compatible with the patient's own tooth color and/or tooth translucency.[36] In our study, the increase in the number of discoloration complaints in the second decade could be associated with the patients' increased interest in aesthetic brackets in the second decade compared to the first decade. Accordingly, it is highly important to select the most appropriate brackets according to patients' aesthetic expectations and individual characteristics and to inform the patients about the risk of discoloration.

Our study was limited in several ways. First and foremost, the language used was not English. Nevertheless, EksiSozluk is used more interactively than many international English-language collaborative hypertext dictionary sites and has an important role in setting the agenda and influencing people's preferences in Turkey.[10,15,19] The second limitation was that the entries were not graded with regard to their accuracy and quality. In the literature, there are various indexes used for rating websites and videos.[6–8] However, it is not possible to adapt these indexes since the contents of the entries (objective information showing scientific sources as well as news, humor, or personal experiences) and their lengths show remarkable variation. Finally, it is a common fact that collaborative hypertext dictionary sites allow their contributors to delete their titles and entries in later periods. Accordingly, the statistical findings obtained in our study, though confirmed at the end of the study, may show time-related differences due to this dynamic process.

CONCLUSION

The results indicated that the contributors' attitudes towards orthodontic treatment shifted from negative in the first decade to positive in the second decade. Nonetheless, it should be noted that the contributors expressed serious negative attitudes and complaints regarding orthodontic treatment, which need to be addressed appropriately. On the other hand, in the second decade, pain and eating/swallowing problems were the most common complaints while the complaints regarding physical appearance decreased and the complaints regarding prolonged treatment increased. Moreover, the increased number of entries in the second decade compared to the first decade indicate the increased awareness regarding collaborative hypertext dictionary sites.

Ethics Committee Approval: Since the data were collected from publicly available entries, no ethics committee approval was required.

Informed Consent: N/A.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – M.A.Y., M.N.E.; Design – M.A.Y., M.N.E.; Supervision – M.A.Y., M.N.E.; Materials – M.A.Y., M.N.E.; Data Collection and/or Processing – M.A.Y., M.N.E.; Analysis and/or Interpretation – M.A.Y., M.N.E.; Literature Review – M.A.Y., M.N.E.; Writing – M.A.Y., M.N.E.; Critical Review – M.A.Y., M.N.E.

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

Funding: The authors declared that this study has received no financial support.

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TURKISH JOURNAL of ORTHODONTICS

DOI: 10.5152/TurkJOrthod.2022.21256

Original Article

The Perception of Adults and Adolescents of Undergoing and Paying for Tooth Movement Acceleration Procedures in Turkey

Tuğba Haliloğlu Özkan[1], Derya Dursun[2]

[1]Department of Orthodontics, Üsküdar University, Faculty of Dentistry, İstanbul, Turkey
[2]Department of Orthodontics, University of Health Sciences, Faculty of Dentistry, İstanbul, Turkey

Cite this article as: Haliloğlu Özkan T, Dursun D. The perception of adults and adolescents of undergoing and paying for tooth movement acceleration procedures in Turkey. *Turk J Orthod.* 2022;35(4):2844-289.

Main Points

- Adults desire a shorter orthodontic treatment time than adolescents.
- Financial concerns regarding reduced treatment time greatly influence patient preferences in Turkey.
- Nearly half of the patients were willing to undergo an adjunctive procedure to improve their treatment time.

ABSTRACT

Objective: The aim of this study is to evaluate the opinions of adolescents and adults regarding nonconventional methods and their associated payment options in Turkey.

Methods: A total of 183 subjects were asked to complete a questionnaire to evaluate their perception of various nonconventional acceleration methods: corticotomy, piezocision, micro-osteoperforation, vibration, drug injection, and customized appliances. The questionnaire also investigated how willing the patients would be to pay more and how much more they would accept to reduce the treatment time.

Results: About 38.7% of the adolescents and 44.4% of the adults were willing to undergo an additional procedure, and 59.6% of both groups chose customized appliances as their first preference as a way of accelerating the treatment process. About 45.4% of the total participants were neutral about paying more to reduce treatment time. Those patients who were willing to pay more accepted a maximum increase of only 10% even if that meant a 50% decrease in treatment time.

Conclusion: Adults were slightly less tolerant of the duration of orthodontic treatment than adolescents and were more likely to undergo additional procedures and pay more for a shorter treatment time. In addition, the invasiveness of each procedure was the primary factor given when choosing an acceleration method, rather than its reduction rate.

Keywords: Accelerated orthodontics, orthodontics, tooth movement, corticotomy, patient's preference

INTRODUCTION

The duration of orthodontic treatment varies from several months to 3 years, with a mean treatment time of 19.9 months for fixed appliances, which can be considered as a long time. Prolonged treatment time not only affects the psychosocial state of the patient but also increases the risk of periodontal disease, tooth decay, and root resorption.[1] However, 74% of adolescent patients and 42% of adult patients have a desire for an orthodontic treatment that takes less than 12 months.[2] Therefore, shortening the treatment time seems to be of critical importance for both the clinician and the patient.

To date, various interventions, including local injection of cellular mediators,[3-6] physical–mechanical stimuli,[7-11] and surgically assisted orthodontics,[11-13] have been suggested as adjunctive methods to reduce the treatment

Corresponding author: Tuğba Haliloğlu Özkan, e-mail: dttuuba@gmail.com

Received: December 15, 2021
Accepted: April 28, 2022
Publication Date: December 30, 2022

time. Although prostaglandins, parathyroid hormone, and vitamin D3 show positive outcomes as chemical applications,[14-16] the idea of administering an extra drug into the body that may cause side effects can be unsettling for patients. Similarly, corticotomy, piezoincision, and micro-osteoperforation have been suggested as effective methods[11-13] which present promising results in decreasing treatment time. However, these methods require surgical intervention to the bone, periosteum, and mucosa, which can be unpleasant for the patient. As a mechanical stimulation method, vibration is a developing noninvasive modality[17] which might be considered as a more acceptable method by patients, that is, apart from its extra cost. The use of computer-designed customized appliances also resulted in shorter treatment times, but this benefit still remains to be validated before recommending it to patients as an acceleration method.[18] Moreover, the fact that their costs are higher than conventional appliances prevents patients from requesting them. As an overall result, patients are quite hesitant about accepting the aforementioned methods, considering their aggressiveness, side effects, and extra costs.

While research continues to identify the best method to accelerate tooth movement (by considering the application protocols, side effects, and cost-benefit analysis), patients' acceptance of these methods seems to be the most important part of this issue. Therefore, the aim of this study was to evaluate patients' perception and acceptance of undergoing and paying for different nonconventional tooth acceleration methods as being adjunctive to their orthodontic treatment. The null hypothesis was that there would be a significant difference in the perception of adults and adolescents regarding the acceleration methods.

METHODS

This cross-sectional survey was conducted in the orthodontic department of University of Health Sciences, Faculty of Dentistry from November 2020 to January 2021. Ethical approval was obtained from the ethical committee of University of Health Sciences (no.: E-31936). The questionnaire used in this study was adopted from a previous study[2] and consisted of multiple choice questions (n = 3), ranking questions (n = 2), and 5-point Likert scale questions (n = 10) (Appendix A). Written consent was obtained from each respondent. Data were collected face to face from participants via a written document to ensure that the adolescents clearly understood the acceleration methods. The inclusion criteria to participate in the survey were as follows: to be older than 12 years of age, to be currently receiving orthodontic treatment, and to be able to read and speak Turkish proficiently. Patients who were younger than 12 years of age, who were already using any of the methods to decrease treatment time and who were suffering from mental disorders were excluded.

The first page of the survey included a brief summary of the following 6 acceleration methods with an explanatory picture of each procedure: corticotomy, piezoincision, micro-osteoperforation, vibration, drug injection, and customized appliances. The questionnaire included a total of 15 questions evaluating the following issues:

- Demographics (age and gender),
- Perception of the orthodontic treatment duration (questions: 1-5),
- Willingness to undergo adjunctive methods to accelerate tooth movement (questions: 6-11),
- Preferences related to reduced treatment time (questions: 12-13),
- Willingness to make extra payment for the acceleration methods (questions: 14-15).

Adolescents were asked to answer the first 13 questions. Questions about the willingness of payment (questions: 14-15) were only asked to the parents of the adolescents. Adults were expected to answer all the questions.

Statistical Analysis

Descriptive statistics were used to determine frequencies and percentages. Group comparisons were conducted using the Mann–Whitney U-test for gender and the Kruskal–Wallis test for age. The Statistical Package for Social Sciences for Windows version 15.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses. The level of significance was set as $P < .05$. Statistical power analysis was used to determine the number of samples at $\alpha = 0.05$, power of the test at 90%. The sample size calculation was carried out with reference to a previous study.[19] A 20% difference in the perception of adults and adolescents, which was adopted to be clinically meaningful, was detected to calculate the sample size.

RESULTS

Adolescents, their parents (n = 111), and adults (n = 72) were included in this study. About 40.4% of samples were male (n = 74) and 59.6% of them were female (n = 109) (Table 1). The participants were at various stages of orthodontic treatment, ranging from 0 to 28 months and 39.3% of them agreed that orthodontic treatment takes too long. About 31.7% of the participants had neutral feelings regarding the duration of treatment. About 34.2% of the adolescents stated that they expected an orthodontic treatment period of 12-18 months while 40.3% of adults gave this period as 6-12 months. About 43.2% of adolescents were neutral while 58.3% of adults were willing to undergo an additional procedure (Table 2). About 54.1% of females stated they would choose to undergo an additional procedure, while 47.3% of males were neutral about this point. Only 9.9% of adolescent and 5.6% of adult participants had prior knowledge of "accelerated orthodontics." In addition, almost all male participants (97.3%) gave a negative response to this question.

Table 1. Demographic data of participants

	Gender		
Participants	F	M	Mean Age
Adolescent	75	36	16.27 ± 1.22
Adult	34	38	24.13 ± 1.28

Table 2. Perceptions about orthodontic treatment duration and willingness for undergoing and paying for adjunctive procedures

Item	Response	Adolescents	Adults	*P*
Treatment duration	<6 months	16.2%	23.6%	.325
	6-12 months	27%	16.7%	
	12-18 months	18.9%	26.4%	
	18-24 months	17.1%	15.3%	
	>24 months	20.7%	18.1%	
How strongly do you agree that orthodontic treatment takes too long?	Strongly disagree	2.7%	4.2%	.582
	Somewhat disagree	16.2%	18.1%	
	Neutral	36%	25%	
	Somewhat agree	36%	44.4%	
	Strongly agree	9%	8.3%	
How long would you wish to be in braces?	<6 months	12.6%	9.7%	.190
	6-12 months	32.4%	40.3%	
	12-18 months	34.2%	20.8%	
	18-24 months	18.9%	23.6%	
	>24 months	1.8%	5.6%	
Acceptance of an additional procedure to reduce treatment time	Strongly disagree	0.9%	4.2%	.054
	Somewhat disagree	11.7%	5.6%	
	Neutral	43.2%	31.9%	
	Somewhat agree	38.7%	44.4%	
	Strongly agree	5.4%	13.9%	
Would you be able to pay higher monthly payments to reduce your treatment time?	Strongly disagree	6.3%	2.8%	.407
	Somewhat disagree	15.3%	19.4%	
	Neutral	49.5%	38.9%	
	Somewhat agree	23.4%	31.9%	
	Strongly agree	5.4%	6.9%	

The level of significance was set as $P < .05$.

About 66.7% of adolescents and 76.4% of adults expressed a preference for having treatment using customized appliances to accelerate their treatment and 59.6% of all participants ranked this treatment modality as their first option (Table 3). Drug injection was the second most preferred option (22.4%). About 48.1% of the total participants selected corticotomy as the last option. When advised with a 25%-30% reduction in treatment time, customized appliances (59.6%) and drug injection (22.4%) were the most ranked 2 modalities. Micro-osteoperforation was the third most preferred option (8.7%), and vibration was the fifth (1.6%) (Table 4). For the question querying the "reduction in treatment time that would be attractive to try these alternative treatment modalities," 60.7% of participants chose "customized appliances with 30% reduction" as the first option and "drug injection with 25% to 30% reduction" as the second most preferred option. Surprisingly, "vibration with 30% reduction" was chosen as the

Table 3. Willingness to undergo different nonconventional acceleration procedures

	Customized Appliances		Corticotomy		Piezoincision		Micro-osteoperforation		Vibration		Drug Injection	
Response	1	2	1	2	1	2	1	2	1	2	1	2
Very unwilling	1.8%	0%	30.6%	22.2%	29.7%	23.6%	18.9%	13.9%	9%	4.2%	5.4%	9.7%
Somewhat unwilling	8.1%	5.6%	21.6%	40.3%	24.3%	36.1%	30.6%	34.7%	22.5%	15.3%	27.9%	18.1%
Neutral	23.4%	18.1%	26.1%	18.1%	28.8%	19.4%	30.6%	22.2%	28.8%	20.8%	34.2%	36.1%
Somewhat willing	53.2%	50%	20.7%	15.3%	17.1%	16.7%	19.8%	27.8%	32.4%	50%	27%	29.2%
Very willing	13.5%	26.4%	0.09%	4.2%	0%	4.2%	0%	1.4%	7.2%	9.7%	5.4%	6.9%

1, Adolescents; 2, Adults.

Table 4. Willingness to undergo different adjunctive procedures advised with a 25% to 30% reduction in treatment time

		Willingness (%)					
Methods	**Group**	**1**	**2**	**3**	**4**	**5**	**6**
Customized appliances	Adolescents	60.4%	2.7%	6.3%	18.9%	6.3%	5.4%
	Adults	58.3%	4.2%	8.3%	20.8%	5.6%	2.8%
Drug injection	Adolescents	18.9%	4.5%	10.8%	53.2%	5.4%	7.2%
	Adults	27.8%	0	15.3%	44.4%	6.9%	5.6%
Corticotomy	Adolescents	0.9%	33.3%	3.6%	15.3%	15.3%	46.8%
	Adults	0	36.1%	6.9%	6.9%	6.9%	50%
Piezoincision	Adolescents	11.7%	9%	48.6%	15.3%	9%	6.3%
	Adults	4.2%	6.9%	40.3%	29.2%	9.7%	9.7%
Micro-osteoperforation	Adolescents	6.3%	21.6%	20.7%	6.3%	24.3%	20.7%
	Adults	6.9%	25%	16.7%	4.2%	31.9%	15.3%
Vibration	Adolescents	13.5%	40.5%	5.4%	9.9%	28.8%	1.8%
	Adults	44.4%	38.4%	14.3%	45%	39.6%	1.4%

last option by 13.7% of all the participants. Across all the surgical modalities offering a 50% reduction in treatment time, micro-osteoperforation was the most preferred option (7.7%).

Of all the participants, 45.4% were neutral about paying more to shorten the treatment time, 32.8% were willing/very willing, and 10.9% were unwilling. About 28.8% of parents of adolescents were willing to pay more to reduce their treatment time while 38.8% of adults were willing to pay more (Table 2). However, while a majority of those adolescents' parents (19.8%) agreed to pay a maximum of 30% increment in fees for a 50% (maximum) decrease in treatment time, adults agreed to pay for only a maximum of 10% in fee for the maximum decrease percentage (Tables 5 and 6). No statistically significant difference was found between responses of adolescents and adults.

Table 5. Responses by adolescents for an appropriate fee increase for a particular reduction in treatment time

Reduction in Time	Increase Amount in Fees				
	10%	**20%**	**30%**	**40%**	**50%**
10%	11.7%	0	0	0.9%	0
20%	2.7%	6.3%	0	0	0
30%	3.6%	3.6%	9%	1.8%	0
40%	0	3.6%	1.8%	0	0
50%	18%	6.3%	19.8%	4.5%	6.3%

Table 6. Responses by adults for an appropriate fee increase for a particular reduction in treatment time

Reduction in Time	Increase Amount in Fees				
	10%	**20%**	**30%**	**40%**	**50%**
10%	6.9%	2.8%	0	0	1.4%
20%	1.4%	4.2%	0	0	0
30%	4.2%	6.9%	1.4%	0	1.4%
40%	0	4.2%	1.4%	1.4%	0
50%	27.8%	2.8%	22.2%	4.2%	5.6%

Substantial differences in ranking for all questions were not found between genders.

DISCUSSION

The current study evaluated adolescents' and adults' perception of nonconventional tooth movement acceleration methods such as corticotomy, piezocision, micro-osteoperforation, vibration, drug injection, and customized appliances along with their willingness to undergo and pay for these methods.

In the current survey, the fact that the participants were in a homogeneous distribution of various treatment periods provided a benefit—it allowed them an objective reflection of their perceptions (Table 2). Nearly half of adolescents and adults agreed that orthodontic treatment takes too long, as it has been stated in previous studies.[19-21] A larger majority of adults desired a shorter treatment time (6-12 months) than adolescents did (12-18 months). This finding is consistent with Umeh et al.[20] who stated that adults were more dissatisfied with treatment duration compared to adolescents. In contrast, Uribe et al.[2] stated that adolescents prefer a shorter period of orthodontic treatment (less than 6 months) than adults. Nearly half (49.7%) of the total patients were willing to undergo an adjunctive procedure to improve their treatment time. Adult patients were more willing than adolescents, however this difference was not found to be statistically significant ($P > 0.05$). Not surprisingly, the majority (91.8%) of the total subjects had never heard about "accelerated orthodontics." This might be due to the fact that these acceleration methods are currently at the hypothesis stage in the literature and have not yet been integrated practically into daily life.

In the current study, when advised with a same amount of reduction (50%) in treatment time, corticotomy was the least favored and the surgical method most ranked last by all patients. However, this is not surprising since surgical procedures have been shown to produce the highest anxiety in patients in a dental setting.[22] Corticotomy has also been reported by patients to be an undesirable procedure in many previous studies.[23] When the acceptance rate of the other 2 surgical methods was compared, there was a slight preference of micro-osteoperforation over piezocision (Table 3). Patients preferred "holes" to "incision" in the bone. When the reduction rate was increased from 25%-30% to 50%, no significant increase was observed in the preference of surgical methods by patients. This indicates that the invasiveness of the procedure is the primary factor when choosing an acceleration method, regardless of its reduction rate. Among the noninvasive methods, use of customized appliances was the option ranked first most, followed by drug injection, by all the subjects. While vibration was favored by almost half of the patients, customized appliances and drug injection preference was higher than vibration. In addition, vibration was the fifth most preferred option among the other methods advised with a 25%-30% reduction in treatment time. These may reflect the fact that patients prefer a one-time procedure administered by a physician compared to an application that they have to do on their own every day. This finding is in contrast with studies reporting that patients prefer using tooth vibrators more than drug injection.[20,21] Similar to the results of this survey, customized appliances have been reported as the most preferred noninvasive modality in previous studies.[19-21]

In our country, patients receiving orthodontic treatment in state universities are generally patients of moderate socioeconomic status and they are only charged for the orthodontic materials used. This situation also limits the possible effects of the study sample being taken only from a single clinic on the study results. It is therefore not surprising that a huge percentage of the study population would prefer not (neutral/somewhat unwilling/very unwilling) to make an extra payment to accelerate their treatment (67.1%). The adult group was more willing to pay more to reduce their treatment time than the adolescent's parents group. In similar studies, it was stated that patients would prefer to pay no more than 10%-20% to reduce their treatment time.[2-19-20] In the current study, nearly 20% of patients chose a maximum 30% increased payment, even with a 50% decrease in treatment time. Statistically significant differences were not observed between adolescents, their parents, and adults regarding the acceleration methods or the payment preferences.

This study provides a basis for analyzing the different views of adolescents and adults regarding the adoption of new technology to shorten orthodontic treatment time. Regarding study limitations, not all acceleration methods were included in this study and the acceleration rates of the methods included were considered theoretically due to the lack of proven data in the literature. This study was conducted in a single state university; therefore, private orthodontic practices in different regions of the country could be included in any future studies. In addition, other adjunctive methods for reducing treatment time could be added.

CONCLUSION

For both adolescents and adults, the invasiveness of the acceleration methods used is the primary issue to resolve. In addition, financial concerns greatly influence patient preferences. Future studies should primarily focus on acceleration methods being less invasive and less costly rather than focusing on increasing their effectiveness in order to shorten the duration of orthodontic treatment.

Ethics Committee Approval: Ethics committee approval was received from the Ethical Committee of University of Health Sciences (approval number: E-31936).

Informed Consent: Written consent was obtained from each respondent.

Peer-review: Externally peer-reviewed.

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

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

Funding: The authors declared that this study has received no financial support.

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TURKISH JOURNAL of ORTHODONTICS

DOI: 10.5152/TurkJOrthod.2022.21116

Original Article

Biometric Assessment of Temporomandibular Disorders in Orthodontics: A Multi-arm Randomized Controlled Trial

Raj Kumar Maurya[1], Harpreet Singh[2], Brijinder Talwar[1], Poonam Sharma[2], Pranav Kapoor[2]

[1]Orthodontics, Central Government Dental Unit, Nagaland, India
[2]Department of Orthodontics and Dentofacial Orthopedics, ESIC Dental College and Hospital, Rohini, Delhi, India

Cite this article as: Kumar Maurya R, Singh H, Talwar B, Sharma P, Kapoor P. Biometric assessment of temporomandibular disorders in orthodontics: A multi-arm randomized controlled trial. *Turk J Orthod.* 2022;35(4):290-306.

Main Points

- The use of biometric equipment is a viable diagnostic and therapeutic modality, offering the advantages of non-radiating and easily reproducible digital quantitative assessment and documentation of temporomandibular disorder (TMD) signs and symptoms.
- Comprehensive fixed orthodontic mechanotherapy does not aggravate TMDs. Temporomandibular disorders attributable to unstable orthodontic malocclusion can be treated successfully with comprehensive orthodontic treatment.
- Temporomandibular disorders due to multifactorial temporomandibular joint (TMJ) and muscular components may usually require adjunctive splint therapy for at least 3 months.

ABSTRACT

Objective: This randomized controlled trial aimed to evaluate the role of fixed orthodontic treatment in the aggravation, precipitation, or alleviation of temporomandibular disorders in young adults.

Methods: Sixty patients were randomly assigned to 4 groups of 15 patients each (group I, orthodontic treatment in temporomandibular disorder-free orthodontic patients; group II, orthodontic treatment in patients with mild symptoms of temporomandibular disorders; group III, splint therapy accompanied by orthodontic treatment in patients with moderate symptoms; and group IV, control with no treatment). The biometric equipment used were the T-scan, to analyze the occlusal component; the BioEMG for muscular analysis; BioJVA for temporomandibular joint acoustic analysis; and JT3D for mandibular kinematic analysis. The paired *t*-test and ANOVA were used for intragroup and intergroup comparisons, respectively. The difference between groups was assessed using post hoc Tukey's test.

Results: Groups I and III showed significant difference in the occlusal, muscular, temporomandibular joint vibration, and kinematic mandibular assessment variables. Group II showed significant improvement in occlusal variables only. Group IV did not show improvement in any of the variables except for certain muscular components.

Conclusion: Successful practical utilization of biometric equipment revealed that fixed orthodontic treatment does not aggravate temporomandibular disorders. It was also found that temporomandibular disorders due to malocclusion can be treated successfully with orthodontic treatment, whereas temporomandibular disorders due to multifactorial temporomandibular joint and muscular components might require splint therapy before orthodontic intervention.

Keywords: JT3D, BioEMG, BioJVA, orthodontic treatment, temporomandibular disorder, T-scan

BACKGROUND

As the dentition is an integral component of masticatory system and plays an important role in maintaining harmony of temporomandibular joint (TMJ), malocclusions such as open bite, deep bite, and posterior crossbite

Corresponding author: Harpreet Singh, e-mail: drhpreetesic@gmail.com

Received: May 20, 2021
Accepted: December 12, 2021
Publication Date: December 30, 2022

have often been reported to be associated with temporomandibular disorders (TMDs) by various researchers.[1,2,3]

Temporomandibular disorders are a collective heterogeneous group of pathologies affecting masticatory apparatus with signs and symptoms of pain, myalgia, limited mouth opening, jaw clicking, crepitus, and subluxation. The myriad treatment approaches include remedial measures, pharmacological therapy, and splint therapy, as well as occlusal rehabilitation by orthodontics, prosthodontics, or surgical procedures.[4]

The possible pathognomic role of orthodontic therapy in precipitation of TMDs, whether at predisposing, initiating, or perpetuating levels, has been widely studied and often debated, especially following a well-publicized lawsuit ascribing orthodontic treatment as a main causative factor of TMJ pain after treatment.[5] However, a recent cross-sectional retrospective study by Manfredini et al.[6] demonstrated the relationship between orthodontic treatment and the presence of specific symptoms of the TMJ to be a "casual" one rather than "causal" one, thereby indicative of the neutral role of orthodontics in TMDs. Several other researchers also concurred, and no obvious cause–effect relationship between orthodontics and TMDs was reported.[7-10] Furthermore, extensive reviews and a few prospective studies have also concluded that irrespective of the orthodontic technique and mechanics employed, the extraction or non-extraction protocols and the type of presenting malocclusion, orthodontic therapy does not precipitate or increase the risk for development of TMD signs and symptoms.[11-16] Even so, the conflict has not been fully settled, as some studies have even reported less-prevalent TMD signs and symptoms in orthodontically treated patients compared with untreated subjects.[16,17]

Moreover, even with existence of well-designed studies elucidating the TMD–orthodontic interrelationship, there is lack of strong evidence-based literature and some orthodontists still suffer from anecdotal testimonials.[18] Thus, the need to supplement evidence-based literature with randomized controlled clinical trials has been stressed quite often.[7] The major limitation in delineating the role of orthodontic treatment for quantification of TMDs signs and symptoms is the lack of resources. With recent reports[3,19] documenting a higher prevalence of pre-existing painful TMD signs and symptoms in patients seeking orthodontic treatment, assessment of the masticatory system, and TMD signs/symptoms using simple TMD-related diagnostic screening and monitoring instruments becomes even more pertinent and indispensable prior to the initiation of orthodontic therapy. Literature has reported analyses based on case history, clinical examination, questionnaire, or radiographic assessments. Paesani et al.[20] reported accuracy of detection of TMDs using the inspection and palpation method, to be as low as 43–50%. With the advent of digital technology, it has been possible to assess the TMJ and associated masticatory complex, not only qualitatively but also quantitatively, which was practically not possible in earlier times. These equipment can be classified based on functional assessment capacity in relation to the craniofacial complex: examples are the digital occlusal analyzer, dynamic masticatory muscle recording devices, temporomandibular joint sonography, and kinematic assessors of the mandible, of BioRESEARCH diagnostic equipment (BioRESEARCH Associates, WI, USA) and the K7 evaluation system (Myotronics - Noromed, WA, USA). These devices augment human intelligence by quantifying occlusion, muscular activity, and TMJ using various parameters such as the dynamic graphical representation of occlusion and three-dimensional jaw movement, which augments the visual perception of occlusion. Additionally, synchronous guidance of muscle and TMJ using BioJVA and EMG aids in augmentation of the tactile assessment of the stomatognathic system.

Though isolated clinical utility of biometric-based bio-medical equipment in diagnosis and treatment planning in neuromuscular dentistry has been reported, till date, no study has reported the role of the muscular, occlusal, or TMJ components of TMDs using the above-mentioned biometric assessment devices in unison.[20-24] The null hypothesis was formulated that that there would be no precipitation, aggravation, or alleviation of TMDs after orthodontic treatment with or without splint therapy.

METHODS

The present study was conducted in accordance with the Declaration of Helsinki ICH Good Clinical Practice guidelines, with Institutional Ethical Committee approval vide letter number 14/IEC/ADCRR/2017, as a multi-arm randomized controlled trial (m-RCT).

Trial Design

i. Multi-arm design with 1 : 1 : 1 : 1 allocation ratio.
ii. No change in trial design was carried out while conducting the trial.

Eligibility Criteria

Patients enrolled for the trial met the following inclusion criteria: (a) all permanent dentition till the second molar minimum in both arches; (b) orthodontic malocclusion, either Angle's Class I, Class II, or Class III; (c) Piper Classification of TMD I, II, or IIIa; (d) Research and Diagnostic Criteria for Temporomandibular Disorders (RDC-TMD), criteria Ia, Ib, and IIa; and (e) symmetrical face with no gross mandibular asymmetry.

Dental occlusion was assessed on the basis of the following morphological occlusal dental relationships: overjet, overbite, crossbite, scissor-bite, anterior open bite, midline discrepancies, and presence of crowding/spacing in each arch. The clinical registration of retruded contact position to maximum intercuspation (RCP-MI) slide length was done in the 3 spatial axes following manual mandibular manipulation. When the RCP-MI slide value was less than 2 mm, it was considered "normal," and as "present" when the value was greater than or equal to 2 mm.[6]

As for the distribution of Angle classes, 38 subjects exhibited Class I malocclusion, 14 exhibited Class II, and 8 exhibited Class III malocclusion. Cephalometrically, the subjects with Class I malocclusion exhibited the following characteristics: upper incisor to S-N plane angle (U1-SN) > 102°, lower incisor to mandibular plane angle (L1-Mand) > 99°, interincisal angle less than 124.8°, and normal to mild hyperdivergent growth pattern. Patients with Class II malocclusions had ANB angle between 4° and 7° with a hyperdivergent growth pattern, proclined maxillary, and proclined/retroclined mandibular incisors. Class III patients exhibited maxillary retrognathism (SNA ≤ 80°), ANB angle between 0° and −4° along with average to hypodivergent growth pattern. Dentally, Class III patients presented with retroclined upper incisors and anterior crossbite, and demonstrated the ability to achieve an edge-to-edge incisor position in retruded contact position. Negligible to minimal dental compensation was observed in the maxillary and mandibular incisors. The saddle, articular, and gonial angles ranged between 118° and 128°, 138° and 148°, and 124° and 135°, respectively, for included patients with Class I malocclusion; and between 110° and 120°, 135° and 140°, and 130° and 137°, respectively, for included Class III malocclusion. However, the articular angle was slightly larger (147° and 153°) and posterior facial height was slightly reduced due to clockwise rotation of the mandible in Class II subjects.

The exclusion criteria were as follows: (a) orthodontic malocclusion requiring surgery; (b) severe TMDs such as Piper IIIb, IVa, IVb, Va, and Vb, and RDC-TMD IIb and above; (c) mixed dentition or permanent dentition with less than 28 teeth; (d) cleft-lip palate and syndromic patients; (e) presence of facial asymmetry and condylar hyperplasia; and (f) history of orthodontic treatment.

Settings and Locations Where the Data Were Collected

The present study was conducted in the Department of Orthodontics, Tertiary Care Dental Institution from 2017 to 2020, and being reported as per extension of CONSORT guidelines-2010 for multi-arm RCT.[25] The trial was registered with the Central Trial Registry of India vide trial registration number CTRI/2019/02/017534.

Interventions

Groups were divided into 4, according to categories of TMD severity assessed using the Fonseca Anamnestic Index (FAI)[26] (Figure 1):

Group I (n = 15) requiring fixed orthodontic treatment, who had no TMD symptoms, such as absence of clicking, muscle pain, limited jaw opening, or deviation. Mean FAI Score of Group I = 0

Group II (n = 15) requiring fixed orthodontic treatment, who had mild TMD symptoms, such as the presence of clicking, muscle pain, limited jaw opening, or deviation. Mean FAI Score Group II = 23.53.

Group III (n = 15) requiring splint therapy followed by fixed orthodontic treatment, who had moderate TMD symptoms such as presence of clicking, muscle pain, limited jaw opening, or deviation. Mean FAI Score Group III = 60.

Group IV (n = 15) acted as control, comprising 15 patients from the hospital staff, who had mild to moderate TMD symptoms such as presence of clicking, muscle pain, limited jaw opening, or deviation. Patients not willing to undergo any therapeutic interventions but agreeing for follow-up constituted the controls. Mean FAI Score Group IV = 30

Case history, clinical examination, and routine orthodontic essential diagnostic investigations such as photographs, OPG, lateral cephalograms, and study models were carried out before and after treatment. Complete TMJ evaluation was done clinically, and features assessed in accordance with RDC (TMD) guidelines[27] and the Fonseca Anamnestic index.[26] The FAI, comprising 10 questions with 3 possible answers: "Yes" (10 points), "No" (0 points), or "Sometimes" (5 points), was utilized to classify patients based on TMD severity by summating the scores of all the questions: absence of TMD (0-15 points), mild TMD (20-40 points), moderate TMD (45-65 points), and severe TMD (70-100 points). Fifteen patients (33%) were treated without extractions, while 30 patients (67%) underwent premolar extractions. Four premolars were extracted in 24 patients, while 2 maxillary premolars were extracted in the remaining 6 patients. In non-extraction cases, the methodology employed included consolidation of existing spaces, interproximal stripping, and en-masse distalization for retraction of upper and lower incisors. The average duration of treatment varied from 18 months to 32 months among all groups.

The centric stabilization splint (CSS), with a smooth surface permitting for free multidirectional contact movements, preferably from and to a centric jaw position, was used for a period of 3-6 months for condylar guidance before institution of active orthodontic therapy in Group III patients (Figure 2). Based on subjective reporting and clinical examination involving the bilateral manual manipulation technique, the patients in Group II did not show any centric relation occlusion and maximum intercuspal position discrepancy, nor any tendency toward dual bite, thereby indicating orthopedically stable joint position of the mandible. Hence, splint therapy was not used in Group II patients. For visualization and determination of the quantitative amount of centric relation/centric occlusion discrepancies in 3 spatial planes, pretreatment dental models were mounted on a semi-adjustable articulator. The full maxillary coverage acrylic splint was fabricated according to a centric bite registration while ensuring that the maxillary flat acrylic occlusal pad touched every buccal cusp or incisal edge of the mandibular teeth. Following delivery of the splint, regular follow-ups were scheduled at 4-week intervals during which the condylar position was assessed with a mandibular position indicator device. At each visit, adjustments were made by reducing the vertical dimension of the splint in order to maintain a flat occlusal plate and an optimal mutually protected occlusion in accordance with Klasser and Greene's recommendations,[28] patients were instructed to wear splints for a minimum of only 12 hours per day to avoid permanent damage to TMJ structures. Evaluation of improvement in TMD symptoms following splint therapy was performed directly by TMJ palpation and muscle palpation tests, and indirectly using the pain intensity questionnaire. Quantitative evaluation of pain was done using a 10-cm long visual analog scale (VAS) with extremes labeled as "No pain" and "Worst possible pain." For assessment of patient's response to palpation of the lateral surface of TMJ,

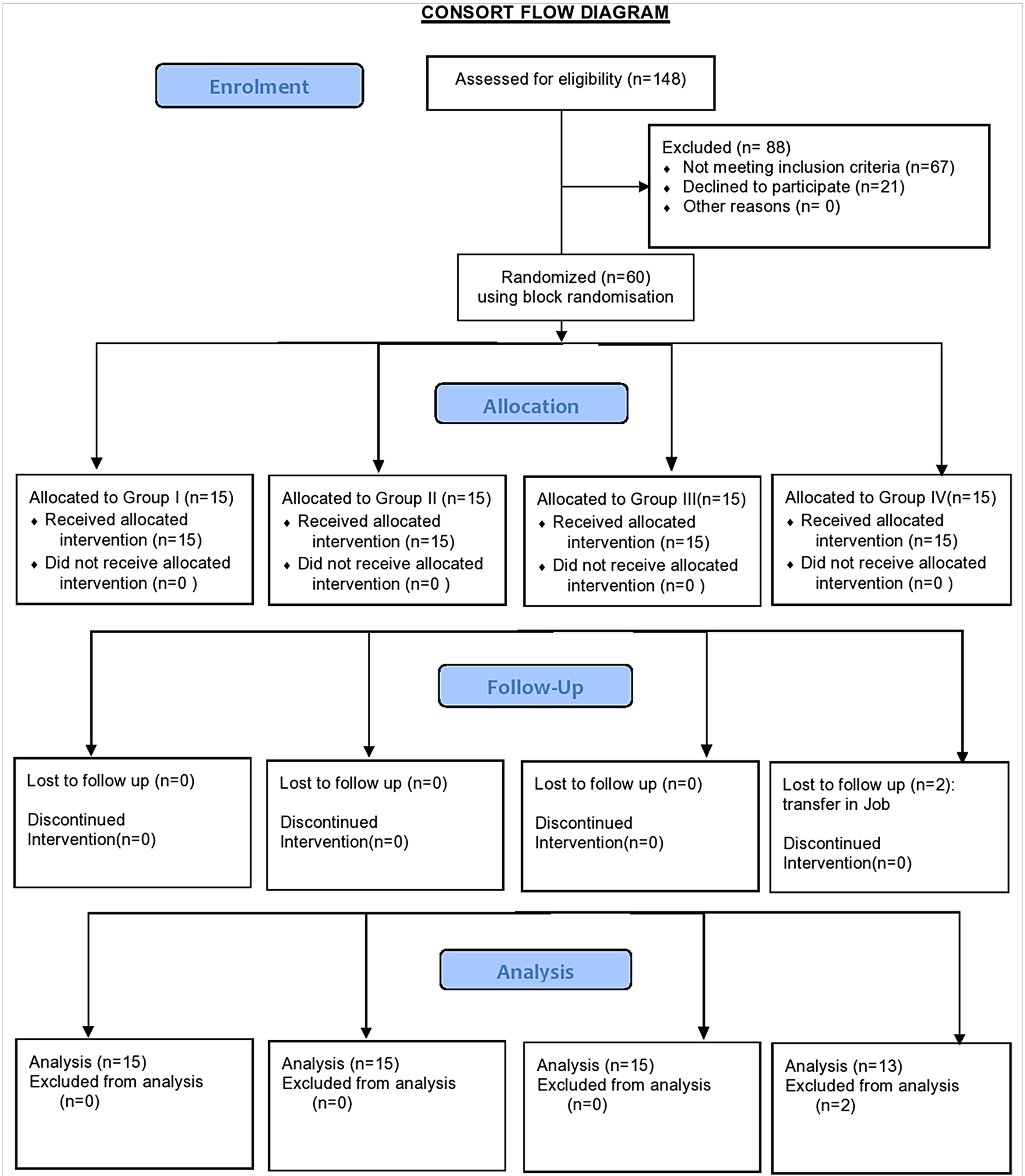

Figure 1. Consort flow diagram depicting the randomization process

the VAS with scores ranging from 0 to 3 was utilized: 0 indicates absence of pain on palpation; 1, mild pain; 2, moderate pain; and 3, severe pain, palpebral reflex, or "jump sign."[29] As for the muscle tenderness, the direct palpation method was employed for the anterior temporalis (posterior, medial, and anterior) and masseter (superficial and deep) muscles. The activity and tenderness of the lateral pterygoid and medial insertion of medial pterygoid were checked indirectly during contraction, using the resistance of fingers or hands of the examining physician. Based on the patient's response, each muscle was also scored from 0

Figure 2. Centric stabilization splint used for Group III patients

to 3 points according to the tenderness on palpation: 0, normal tone; 1, mild tenderness; 2, moderate tenderness; and 3, severe tenderness.[30]

Outcomes

Once the treatment plan was formulated and before placement of appliances, all the 60 patients underwent biometric data recording at T_0 (pretreatment) involving digital occlusal analysis using the T-Scan™ (T-Scan III, version 10.0.1, Tekscan Inc., Boston, MA, USA), Electromyography using BioEMG™ (BioRESEARCH Associates Inc., WI, USA), TMJ Vibration analysis using BioJVA™ (BioRESEARCH Associates Inc.), and mandibular movement analysis using JT3D™ (BioRESEARCH Associates Inc.). The same data were recorded after satisfactory completion of treatment, at T_1.

Digital Occlusal Analysis: The 7 variables of occlusal forces were recorded, that is, distribution of maximum bite forces on the right and left sides and anterior and posterior sides along with disclusion time in the right and left lateral excursions (Figure 3). The T-scan consists of a hardware device, a pressure-sensitive and corresponding tray in large and small sizes, and corresponding software (version 10.0.1). The sensor used in the system was ultrafine plastic with a thickness of 0.004 inches. The software interface allowed for provision of patient recording, archiving, and integration with BioPAK software for other devices such as BioEMG. First, the patient was asked to sit upright comfortably on the dental chair with the occlusal plane parallel to floor. The sensor tray was selected based on the clearance of buccal corridor all over the teeth in maximum occlusion position. The mesiodistal widths of the upper and lower central incisors were recorded with digital Vernier calipers (AEROSPACE, Shanghai, China). Once the tray size of sensor was established, it was attached with the T-scan device, which was connected to the laptop through the USB mode. Patients were shown, by demonstration, the desired mandibular movements to be recorded. They were then instructed to repeat the same 3 times for each movement, that is, maximum biting, and right lateral and left lateral excursion. The sensitivity of optimal biting forces was considered appropriate in case of display of a couple of pink vertical towers mixed with blue and dark blue towers. The average of 3 recordings was taken for analysis.

Digital Muscular activity recording: Chair-side kinematic assessment of activity of the muscles of mastication was done using the surface EMG machine of Bio-EMG™ (Figure 4). The present study utilized 4 channels to record masseter and temporalis activity. The BioEMG equipment allowed the clinician to evaluate the efficiency of the patient's musculature during rest, chewing, and clenching. The electrodes were inserted in the BioEMG amplifier and hung around the patient's neck with a strap. The other end of the electrodes was attached over the skin of the temple region, just above the lateral third of the eyes for anterior temporalis and around

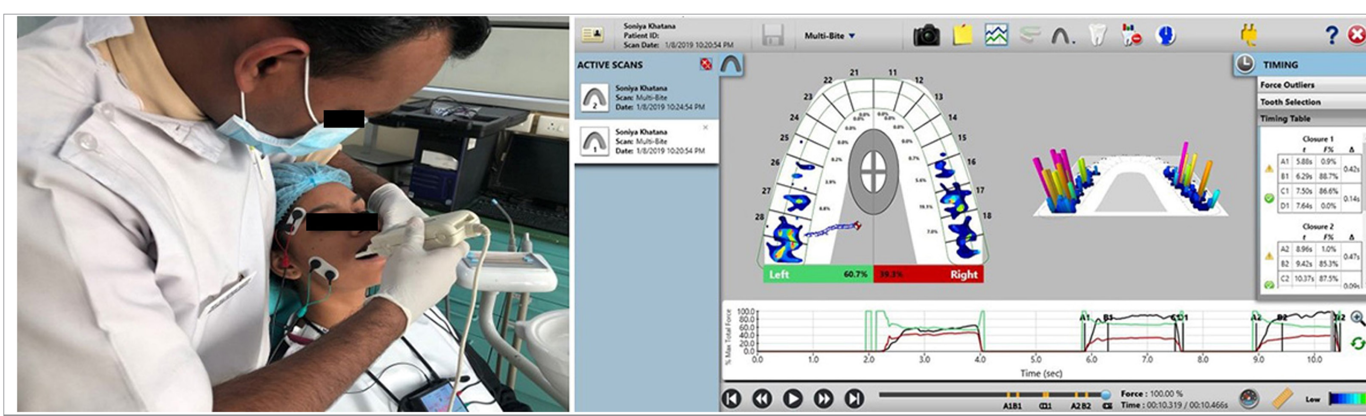

Figure 3. Multi-bite T-scan representing quadrant-wise force distribution and disclusion time

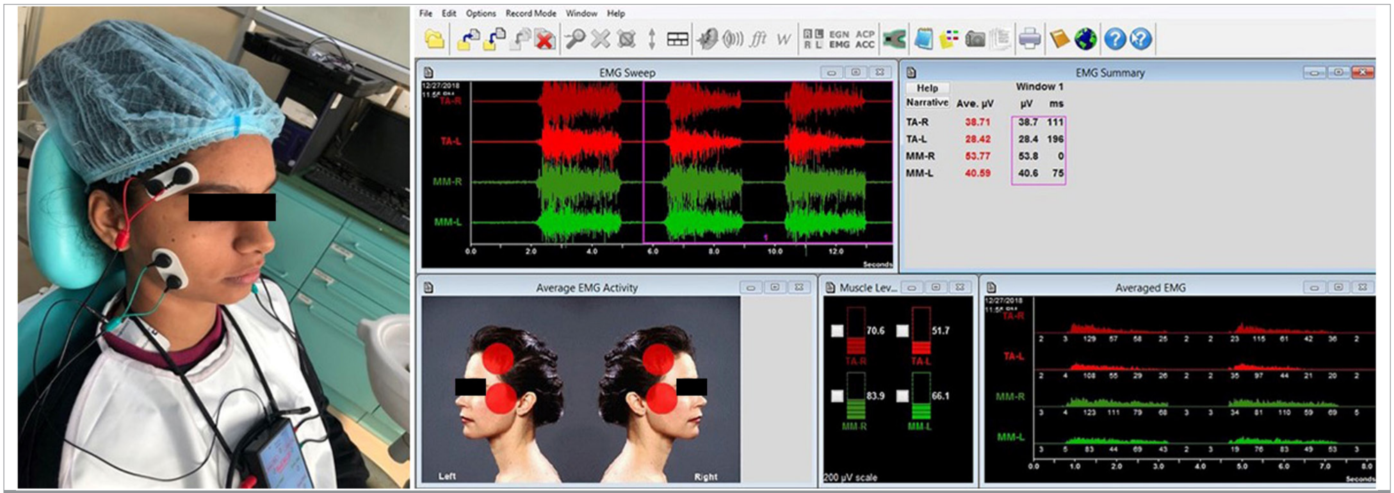

Figure 4. Assessment of activity of temporalis and masseter muscles using BioEMG 4-channel electrode

the anterior border of the mandibular ramus for masseter activity. The ground earthing was provided from the right supra-clavicular region near the posterior border of the sternocleidomastoid muscle. The desired mandibular movements were recorded during maximum biting, right lateral excursion, and left lateral excursion. The software interface depicted the rhythmic activity of muscle firing as a red and blue graph against the true horizontal *X*-axis. Due to the collaboration of Tekscan and BioRESEARCH firms, the simultaneous assessment of digital occlusal reading and muscular movements was possible for coordinated analysis using BioPAK software. A total of 10 variables depicting right and left masseter and temporalis activity at rest and during clenching were analyzed. The activity index and the asymmetry index were determined with the following formula[31]:

- Asymmetry index = (Root mean $square_{right}$ − Root mean $square_{left}$)/(Root mean $square_{right}$ + Root mean $square_{left}$) × 100
- Activity Index = (Root mean $square_{masseter}$ − Root mean $square_{temporalis}$)/(Root mean $square_{masseter}$ + Root mean $square_{temporalis}$) × 100

TMJ Vibration Analysis: Bio-JVA Joint Vibration Analysis is a unique tool which determines the morphological changes in TMJ components which can cause gritting, clicking, crepitus, and subluxation. It consists of a headphone design with 2 acoustic sensitive transducers which were placed on the TMJ complex externally. The 3.5 mm audio jack of BioJVA was inserted into the BioPAK amplifier console, which was also used for BioEMG. The patient was trained to achieve synchronization with the metronome on the laptop. The recording was depicted as a wave form against the horizontal *x*-axis; and any click, crepitus, or subluxation and normal joint sound was seen as varied amplitude and frequency (Figure 5). A total of 6 variables were assessed, that is, the total integral energy in relation to right and left TMJ, its proportion in relation to 300 Hz for both right and left TMJ, peak amplitude, and peak frequency.

Mandibular Movement Analysis: The JT3D Jaw Tracker equipment was used for measuring the 3 dimensions of mandibular movement. A small magnet was placed on the vestibular side of the lower anterior teeth using a special sticky wax, and a headgear containing a bilateral electromagnetic controller mechanism facilitated sensing of the *xyz* position of the magnet with an accuracy of 0.1 mm (Figure 6a). Physiologic movements which occurred during chewing, and non-physiologic movements such as maximum opening/closing or maximum lateral excursions-border movements were assessed. Exact positions of the mandible were recorded by simultaneous use of the JT3D and the JVA (Figure 6b).

Sample Size

Based on a significance level of α = 5% and 80% power (with an allowable error of 20%), a mean difference of 1.4 along with a

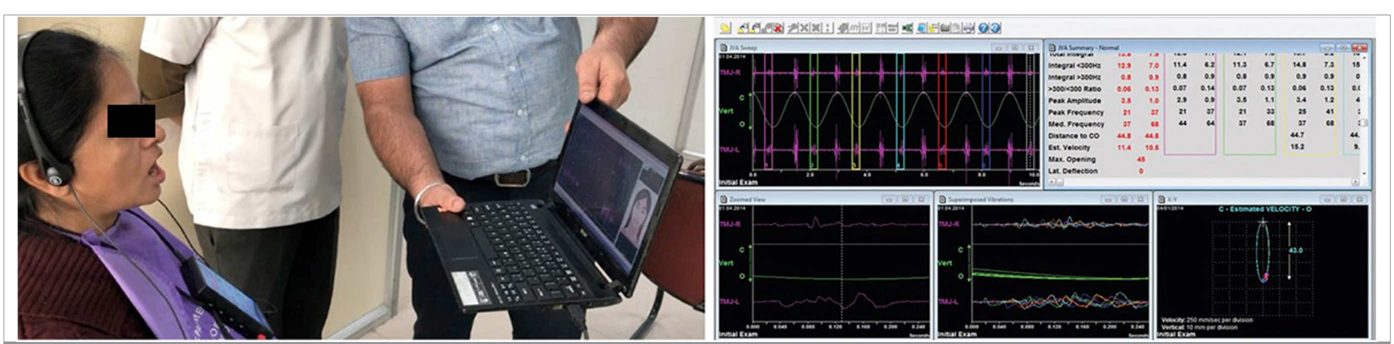

Figure 5. TMJ vibration analysis using BioJVA with the patient trained to achieve synchronization with the metronome on the laptop

Figure 6. a, b. (a) Mandibular movement assessment using Jaw Tracker JT3D (b) Simultaneous representation of TMJ movements and vibrations using BioJVA and Jaw Tracker JT3D

standard deviation 0.8, and considering a 10% drop-out, a minimum sample size of 58 patients was required as confirmed using a sample size calculator, by employing the *t*-statistic (Cytel's East Lite [Cytel Inc., Waltham, MA, USA] application). However, in order to maintain a 1 : 1 : 1 : 1 allocation ratio, a total of 60 patients (29 male, 31 female; mean age: 29.58±5.85), distributed into 15 per group, were recruited in the trial after strict application of the inclusion and exclusion criteria.

Randomization

Sequence Generation

Patients were divided randomly into 4 groups of 15 each with age- and sex-matched controls using the variable permuted block randomization technique. The randomization sequence was generated using Excel 2011 (Microsoft, USA) by employing 2, 4, and 6 sizes of blocks.

Allocation Concealment

The allocation was concealed by using sequentially numbered, opaque, sealed and stapled envelopes which were further made impermeable to light using aluminum foil inside the envelope. The corresponding envelopes were opened only after the enrolled participants completed all baseline assessments and were ready for intervention allocation.

Implementation

The randomization and treatment allocation were done by an independent worker. The treatment procedure was carried out by the principal investigator. The study was carried out with the "intention to treat" for all patients.

Blinding

Blinding was done at data recording and at result assessment levels. To ensure blinding, the entire biometric data recording was done by 2 independent investigators who were not aware about the group of patients. The data interpretation and analysis were done by the principal investigator.

Consent

Informed written consent was obtained from the patients after explaining the entire treatment procedure to them in their native languages.

Statistical Analyis

Data were prepared in the Excel sheet and analyzed using PAST (version 3) statistical software. The Shapiro–Wilk *t*-test was done, and it showed normality of data distribution. There was no statistical difference between age and sex distribution at baseline level ($P > .05$). The pretreatment and posttreatment intragroup comparison was done using the paired *t*-test. The intergroup comparisons between all 4 groups were performed using ANOVA. Tukey's HSD post hoc test was applied to determine the periods at which the measurement changes were significant. The significance level was set at $P < .05$. To account for intraobserver and interobserver errors, reassessments of 30% randomly chosen measurements by the same investigator after 3 weeks and by a second investigator were analyzed with intraclass correlation coefficients, which showed excellent intraobserver and interobserver reliabilities of 0.978 and 0.932, respectively. The reproducibility of double determination of measurements using Dahlberg's formula showed minimal error (within 0.05 mm) that did not affect the reliability of the measurements.

RESULTS

The participant flow diagram according to the PRISMA guidance depicting the numbers of participants who were randomly assigned, received the intended treatment, and were analyzed for the primary outcome for each group along with losses and exclusions after randomization, together with reasons (Figure 1). The distribution of the 4 groups for mean age, gender, malocclusion type, overjet, and overbite are reported in Table 1.

Intragroup comparison of pretreatment and posttreatment measurements within Groups I and III showed significant difference among all T-scan variables except for maximum bite force on the right and left sides (Tables 2 and 4). However, Group II showed significant difference in the right and left differential biting forces and disclusion time (Table 3). There was no significant difference in Group IV in relation to any occlusal variables (Table 5).

Pretreatment intergroup comparison using ANOVA found statistically significant difference for all variables except maximum bite forces on the right and left sides and their differential (Table 6). Post treatment, significant intergroup difference was observed for right and left disocclusion time, the maximum biting forces' differential between the right and left, as well as in the anterior region (Table 7). However, the post hoc test revealed significant difference between groups I and II, II and III, and II and IV only for the left lateral disclusion time before treatment. Post treatment, Groups I, II, and III showed significant differences from group IV for all occlusal variables except for the maximum posterior biting force (Table S1).

Intragroup comparison between Groups I and III showed statistically significant difference in all the muscular variables. However, Group II and Group IV showed difference only for activity and asymmetry index variables, and left-side masseter activity during function and asymmetry index, respectively (Tables 2, 3, 4, and 5).

An intergroup comparison at pretreatment showed significant difference between Groups I and II, II and III, and II and IV for the right anterior temporalis at rest. Similarly, significant difference was observed between Groups I and II, I and III, I and IV, and II and IV for right masseter activity at rest. At pretreatment, significant differences were observed between Groups I and II, I and III, and I and IV for right anterior temporalis, right masseter, and left masseter muscle at function. However, post

Table 1. Demographic distribution of groups in the total sample

SN	Group	Age	Gender	Malocclusion (Class)	Treatment duration (months)	Overjet (mm)	Overbite (mm)
1	Group I	27.92 ± 5.02	F = 8 M = 7	I = 10 II = 4 III = 1	27.2 ± 4	3.33	4.06 ± 1.33
2	Group II	29.53 ± 5.85	F = 9 M = 6	I = 10 II = 3 III = 2	23.80 ± 3.05	2.66 ± 1.63	4.66 ± 1.34
3	Group III	29.53 ± 6.82	F = 8 M = 7	I = 7 II = 6 III = 2	31.93 ± 3.54	2.86 ± 1.45	4.6 ± 1.4
4	Group IV	31.30 ± 5.42	F = 6 M = 9	I = 11 II = 1 III = 3	18 ± 0	2 ± 1.6	3.15 ± 1.5

Data are presented as mean ± SD where applicable; SD, standard deviation; F, female; M, male.

Table 2. Comparison of pretreatment and posttreatment measurements within Group I by paired *t* test

Assessment Variables T' scan variables	Mean		Mean Difference	95% CI	*P*
	T_0	T_1			
Maximum bite force right side (%)	48.53	51.13	2.60	−6.28 to 11.48	.54
Maximum bite force left side (%)	51.46	48.86	2.60	−5.81 to 11.01	.531
Difference between right and left	28.26	3.06	25.20	18.48 to 31.91	.0001*
Maximum bite force anterior region (%)	10.93	7.26	3.66	2.28 to 5.04	.0003*
Maximum bite force posterior region (%)	89.06	93.00	3.93	2.66 to 5.19	.0002*
Right lateral excursive DT (seconds)	0.64	0.33	0.30	0.18 to 0.43	.0001*
Left lateral excursive DT (seconds)	0.73	0.28	0.44	0.34 to 0.53	.0006*
BioEMG variables					
Right anterior temporalis at rest (microV)	0.94	0.52	0.41	0.22 to 0.61	.002*
Right masseter at rest (microV)	1.02	0.58	0.44	0.26 to 0.63	.0001*
Right anterior temporalis at function (microV)	140.09	117.73	22.35	18.28 to 26.42	.0006*
Right masseter at function (microV)	158.96	134.32	24.63	18.071 to 31.198	.0001*
Left anterior temporalis at rest (microV)	1.02	0.73	0.29	0.18 to 0.40	.0006*
Left masseter at rest (microV)	1.48	1.018	0.46	0.24 to 0.67	.0006*
Left anterior temporalis at function (microV)	148.98	123.13	25.84	22.89 to 28.79	.0006*
Left masseter at function (microV)	161.13	130.92	30.20	24.15 to 36.25	.0006*
Activity index	5.75	4.48	1.27	1.05 to 1.48	.0001*
Asymmetry index	5.11	3.72	1.38	1.10 to 1.66	.0006*
BioJVA variables					
Total integral energy right TMJ	56.20	45.46	10.73	5.46 to 16.00	.0006*
Total integral energy left TMJ	61.13	48.93	12.20	9.23 to 15.16	.0001*
>300/<300 ratio right TMJ	0.18	0.16	0.01	−0.003 to 0.03	.092
>300/<300 ratio left TMJ	0.17	0.16	0.01	0.00 to 0.01	.0006*
Peak amplitude	24.51	21.45	3.06	2.11 to 4.01	.0006*
Peak frequency	71.13	64.66	6.46	4.48 to 8.45	.0006*
JT3D variables					
Maximum vertical mouth opening (mm)	45.33	46.40	1.06	0.14 to 1.99	.044*
Maximum sagittal movement (mm)	5.66	5.63	0.02	−0.09 to 0.14	.694
Lateral left (mm)	3.96	4.10	0.14	−0.02 to 0.30	.091
Lateral right (mm)	4.29	4.49	0.2	0.03 to 0.36	.016*

CI indicates confidence interval; T0, pretreatment; T1, posttreatment.
*$P < .05$ is significant.

treatment, the right anterior temporalis and right masseter at function revealed significant difference between Groups I and II, II and III, I and IV, and III and IV. Similarly, the asymmetry index showed significant difference between Groups I and II, II and III, and II and IV before treatment, and between Groups I and II, I and III, II and III, I and IV,II and IV, and III and IV after treatment (Tables 6, 7, and S2).

Intragroup comparison revealed statistically significant difference among all variables except for differential energy at right TMJ in Group I. However, Group II showed significant difference for 3 variables, that is, peak amplitude and differential at both right and left >300/<300 ratio TMJ. An intragroup comparison between Groups III and IV revealed significant increases in all TMJ vibration parameters (Tables 2, 3, 4, and 5).

An intergroup comparison between Groups III and IV revealed a statistically significant difference for all variables before treatment; however, Group III showed improvement in health but Group IV revealed deterioration. The total integral energy on both right and left sides showed significant difference between Groups I and II, I and III, and I and IV before treatment, and between Groups I and II, II and III, I and IV, and III and IV after treatment. Significant difference was observed between Groups I and III, II and III, I and IV, II and IV, and III and IV for differential ratio of right TMJ before treatment; and between Groups II and III, II and IV, and III and IV for differential ratio of left TMJ before treatment. Both the differential ratios of right and left TMJ showed significant difference between Groups I and IV, II and IV, and III and IV after treatment. The peak amplitude of TMJ sound showed significant difference between Groups I and III, II and III, and III and IV before and after

Table 3. Comparison of pretreatment and posttreatment measurements within Group II by paired *t* test

Assessment Variables	Mean				
'T' scan variables	T_0	T_1	**Mean Difference**	**95% CI**	***P***
Maximum bite force right side (%)	46.80	51.06	4.26	−1.65 to 10.19	.148
Maximum bite force left side (%)	53.20	49.06	4.13	−1.93 to 10.20	.169
Difference between right and left	20.53	4.13	16.40	10.52 to 22.27	.0001*
Maximum bite force anterior region (%)	6.86	6.80	0.06	−2.99 to 3.12	.963
Maximum bite force posterior region (%)	93.13	93.20	0.06	−2.99 to 3.12	.963
Right lateral excursive DT (seconds)	0.39	0.22	0.17	0.084 to 0.26	.0006*
Left lateral excursive DT (seconds)	0.47	0.23	0.24	0.14 to 0.35	.0001*
BioEMG variables					
Right anterior temporalis at rest (microV)	3.04	2.48	0.55	−0.02 to 1.13	.056
Right masseter at rest (microV)	2.96	2.84	0.12	−0.27 to 0.51	.533
Right anterior temporalis at function (microV)	158.00	158.92	0.92	−3.63 to 5.47	.666
Right masseter at function (microV)	177.74	181.31	3.56	−0.95 to 8.08	.112
Left anterior temporalis at rest (microV)	3.38	3.04	0.34	−0.19 to 0.88	.194
Left masseter at rest (microV)	3.48	3.06	0.42	−0.06 to 0.92	.091
Left anterior temporalis at function (microV)	171.22	171.04	0.18	−5.68 to 6.04	.946
Left masseter at function (microV)	175.06	178.26	3.19	−2.62 to 9.00	.253
Activity index	4.70	5.140	0.43	0.12 to 0.75	.011*
Asymmetry index	6.65	6.98	0.32	0.06 to 0.57	.021*
BioJVA variables					
Total integral energy right TMJ	84.60	81.33	3.26	−1.88 to 8.42	.200
Total integral energy left TMJ	87.73	85.46	2.26	−2.19 to 6.72	.301
>300/<300 ratio right TMJ	0.15	0.14	0.004	0.0006 to 0.007	.008*
>300/<300 ratio left TMJ	0.147	0.143	0.003	0.001 to 0.006	.001*
Peak amplitude	22.16	24.12	1.95	0.50 to 3.40	.010*
Peak frequency	63.13	60.66	2.46	−0.33 to 5.26	.089
JT3D variables					
Maximum vertical mouth opening (mm)	44.66	44.86	0.2	−0.46 to 0.86	.687
Maximum sagittal movement (mm)	6.10	6.17	0.07	−0.07 to 0.22	.5
Lateral left (mm)	3.55	3.78	0.22	0.02 to 0.42	.022*
Lateral right (mm)	4.86	4.90	0.04	−0.11 to 0.19	.616

treatment. Similarly, significant difference was observed for peak frequency of TMJ sound between Groups II and III and between Groups III and IV before treatment; and between Groups I and III, II and III, and Groups III and IV after treatment (Tables 6, 7, and S3).

Intragroup comparison of movement analysis revealed statistically significant increases in only mouth opening and right lateral movement in Group I, but only left lateral movement showed significant increase in Group II (Tables 2 and 3). However, all variables showed significant changes in Group III and group IV, except for right mandibular movement in Group IV (Tables 4 and 5).

An intergroup comparison revealed that the maximum sagittal movement showed significant difference between Groups II and III and Groups II and IV before treatment; and between Groups II and IV after treatment. Mandibular movement on the left side showed significant difference between Groups I and III, I and IV, and II and IV before treatment; and between groups I and IV, II and IV, and III and IV after treatment. Similarly, mandibular movement on right side showed significant difference between Groups I and III, II and III, Groups I and IV, and II and IV, both before and after treatment (Tables 6, 7, and S4).

DISCUSSION

As orthodontics changes the position of teeth and jaws which further alters the stomatognathic equilibrium, various proponents have claimed its role in TMD, which often presents a complex diagnostic and management challenge.

The conventional methods routinely employed for analysis of TMDs include proper case history, clinical examination, questionnaires, and advanced supplementary diagnostic imaging

Table 4. Comparison of pretreatment and posttreatment measurements within Group III by paired *t* test

Assessment Variables 'T' scan variables	Mean T_0	Mean T_1	Mean Difference	95% CI	*P*
Maximum bite force right side (%)	53.80	50.66	3.13	−5.79 to 12.06	.464
Maximum bite force left side (%)	46.13	49.33	3.20	−5.76 to 12.16	.456
Difference between right and left	29.53	4.26	25.26	18.96 to 31.56	.0001*
Maximum bite force anterior region (%)	11.66	5.60	6.06	3.17 to 8.96	.0005*
Maximum bite force posterior region (%)	88.46	94.06	5.60	2.49 to 8.70	.0002*
Right lateral excursive DT (seconds)	0.80	0.38	0.41	0.26 to 0.56	.0001*
Left lateral excursive DT (seconds)	0.74	0.37	0.36	0.23 to 0.48	.0002*
BioEMG variables					
Right anterior temporalis at rest (microV)	1.34	0.65	0.69	0.55 to 0.83	.0006*
Right masseter at rest (microV)	2.92	0.87	2.046	1.72 to 2.37	.0006*
Right anterior temporalis at function (microV)	178.89	128.45	50.44	45.09 to 55.79	.0006*
Right masseter at function (microV)	190.24	135.95	54.28	49.13 to 59.43	.0001*
Left anterior temporalis at rest (microV)	2.21	1.006	1.20	0.87 to 1.53	.0006*
Left masseter at rest (microV)	2.35	0.79	1.56	1.26 to 1.85	.0006*
Left anterior temporalis at function (microV)	185.11	140.99	44.11	39.87 to 48.36	.0006*
Left masseter at function (microV)	177.60	175.67	1.92	−7.76 to 11.60	.014*
Activity index	5.14	2.73	2.41	2.19 to 2.62	.0006*
Asymmetry index	5.48	3.42	2.06	1.71 to 2.41	.0006*
BioJVA variables					
Total integral energy right TMJ	81.06	43.60	37.46	32.70 to 42.23	.0006*
Total integral energy left TMJ	75.86	40.80	35.06	26.37 to 43.76	.0001*
>300/<300 ratio right TMJ	0.31	0.18	0.12	0.09 to 0.15	.0001*
>300/<300 ratio left TMJ	0.33	0.19	0.14	0.12 to 0.17	.0006*
Peak amplitude	29.44	17.34	12.09	10.25 to 13.93	.0001*
Peak frequency	74.00	37.33	36.66	29.58 to 43.75	.0006*
JT3D variables					
Maximum vertical mouth opening (mm)	39.86	47.20	7.33	4.69 to 9.96	.0002*
Maximum sagittal movement (mm)	4.80	5.53	0.73	0.53 to 0.93	.0001*
Lateral left (mm)	3.24	3.92	0.67	0.33 to 1.01	.0007*
Lateral right (mm)	2.88	3.74	0.86	0.56 to 1.15	.0001*

such as CT and MRI. Paesani et al.[20] reported high variability, low reproducibility, low repeatability, and subjective interpretation as the disadvantages of conventional methods. The authors also reported that the conventional methods have accuracy as low as 50% in diagnosing TMDs.[21] The MRI, a multiplanar imaging technique, on the other hand, provides an accurate assessment of both the bony and the soft tissues of the TMJ, including the position of the articular disc. It offers the advantages of being non-invasive, radiation-free, and providing superior contrast resolution with lesser bone-related artifacts compared to other imaging modalities. However, the utility of MRI imaging examination should be dictated by the potential ability of the acquired information to influence an already established treatment plan or prognosis.[29,33] High prevalence of detection of small abnormalities in TMJ images of asymptomatic individuals, such as flattening of condyles in older subjects, underline the fact that the results of TMJ imaging do not necessarily correspond to the patient's signs and symptoms.[29,34] Additionally, an overestimation of image findings accompanied by unnecessary irreversible treatment might present a risk, particularly for inexperienced clinicians.[29] Although the International RDC-TMD Consortium guidelines[33] propose utility of MRI imaging as an indispensable stage of a definitive diagnostic procedure from the patient's or research problem's perspective, the high costs/increased expenses and claustrophobia involved limit its use in routine clinical settings. Other methodologies such as CBCT and arthroscopy are too expensive for general orthodontic setup, involve radiation and an invasive component, and require special training and setup. However, the biometric devices used in the present study offer the advantages of being economical, chair-side-friendly, and non-radiating. They also do not require any specialized formal training or supervision.

Table 5. Comparison of pretreatment and posttreatment measurements within Group IV by paired *t* test

Assessment Variables 'T' scan variables	Mean		Mean Difference	95% CI	*P*
	T_0	T_1			
Maximum bite force right side (%)	46.84	47.30	0.46	−1.14 to 2.07	.607
Maximum bite force left side (%)	53.15	52.69	0.46	−1.14 to 2.07	.607
Difference between right and left	21.69	20.46	1.23	−1.79 to 4.25	.451
Maximum bite force anterior region (%)	15.00	15.53	0.53	−0.30 to 1.37	.253
Maximum bite force posterior region (%)	92.92	93.00	0.07	−3.45 to 3.60	.962
Right lateral excursive DT (seconds)	0.60	0.64	0.03	−0.008 to 0.08	.111
Left lateral excursive DT (seconds)	0.72	0.73	0.005	−0.02 to 0.03	.706
BioEMG variables					
Right anterior temporalis at rest (microV)	1.13	1.23	0.10	−0.01 to 0.21	.086
Right masseter at rest (microV)	3.16	3.43	0.27	−0.08 to 0.63	.143
Right anterior temporalis at function (microV)	170.21	170.85	0.64	−1.30 to 2.59	.473
Right masseter at function (microV)	186.11	186.96	0.85	−0.73 to 2.44	.256
Left anterior temporalis at rest (microV)	1.85	1.94	0.09	−0.10 to 0.29	.367
Left masseter at rest (microV)	2.30	2.20	0.10	−0.17 to 0.38	.433
Left anterior temporalis at function (microV)	170.89	172.36	1.46	−0.47 to 3.41	.121
Left masseter at function (microV)	177.26	179.48	2.21	1.20 to 3.22	.001*
Activity index	4.93	4.97	0.03	−0.29 to 0.37	.785
Asymmetry index	5.05	5.25	0.20	0.04 to 0.35	.020*
BioJVA variables					
Total integral energy right TMJ	81.53	87.69	6.15	0.92 to 11.38	.024*
Total integral energy left TMJ	85.84	91.00	5.15	3.09 to 7.21	.0002*
>300/<300 ratio right TMJ	0.21	0.25	0.03	0.006 to 0.06	.002*
>300/<300 ratio left TMJ	0.21	0.25	0.03	0.01 to 0.06	.003*
Peak amplitude	25.08	27.91	2.83	1.21 to 4.44	.004*
Peak frequency	64.84	67.84	3.00	1.08 to 4.91	.008*
JT3D variables					
Maximum vertical mouth opening (mm)	41.46	42.92	1.46	0.21 to 2.71	.032*
Maximum sagittal movement (mm)	4.87	4.98	0.10	0.001 to 0.21	.046*
Lateral left (mm)	2.75	2.83	0.08	0.01 to 0.15	.024*
Lateral right (mm)	3.13	3.21	0.08	−0.03 to 0.19	.156

As for the entire human race, digital automation has been a boon for dentistry as well; it benefits all domains, from examination and diagnosis to therapeutic assistance. The 3 biometric assessments in neuromuscular dentistry include the K7 evaluation system (Myotronics-Noromed, WA, USA), BioRESEARCH Associates, and Tekscan equipment. Our study chose BioRESEARCH Associates' equipment, as occlusal component detection facility was not available in the K7 evaluation system, and the T-scan has been shown to be compatible to other BioRESEARCH devices through BioPAK software.

In the present study, the T-scan Novus was used for digital occlusal analysis. Several investigators demonstrated a high degree of reliability with the T-scan in evaluating occlusal contact distribution.[35-37] The findings of the present study, showing improvement of the occlusal component after orthodontic therapy in all 3 active groups except control, suggest that orthodontic treatment helps in stabilizing occlusion by providing proper incisal and canine guidance, removing CR-CO discrepancy, and establishing mutually protected occlusion. Similar findings were also reported in the study of Agbaje et al.[38] Thumati[23] also reported the improvement in maximum biting force efficiency and reduced disclusion time after orthodontic treatment. The suggested improvement could be justified by the study of Brenan et al.[39] and Henrikson et al.[40] who reported that the masticatory ability was correlated to the number of teeth in contact, positively associated with oral-health-related quality of life and proving beneficial for self-perceived masticatory efficiency.

In this study, we used BioEMG to assess the pretreatment and posttreatment activity of the temporalis and masseter muscles using 4-channel electrodes. In accordance with the findings of Rodrigues Bigaton et al.[41] our study also found a predominant contributory role of the masseter muscle during isometric

Table 6. Comparison of pretreatment measurements between different groups by ANOVA test

Assessment Variables 'T' scan variables	Mean at T_0				ANOVA test	
	Group I	Group II	Group III	Group IV	*F* value	*P*
Maximum bite force right side (%)	48.53	46.80	53.80	46.84	0.81	.489
Maximum bite force left side (%)	51.46	53.20	46.13	53.15	0.83	.482
Difference between right and left	28.26	20.53	29.53	21.69	2.27	.090
Maximum bite force anterior region (%)	10.93	6.86	11.66	15.00	4.85	.004*
Maximum bite force posterior region (%)	89.06	93.13	88.46	92.92	4.08	.010*
Right lateral excursive DT (seconds)	0.64	0.39	0.80	0.60	6.05	.001*
Left lateral excursive DT (seconds)	0.73	0.47	0.74	0.72	4.70	.005*
BioEMG Variables						
Right anterior temporalis at rest (microV)	0.94	3.04	1.34	1.13	39.64	.001*
Right masseter at rest (microV)	1.02	2.96	2.92	3.16	16.73	.007*
Right anterior temporalis at function (microV)	140.09	158.00	178.89	170.21	13.51	.040*
Right masseter at function (microV)	158.96	177.74	190.24	186.11	13.60	.001*
Left anterior temporalis at rest (microV)	1.02	3.38	2.21	1.85	21.55	.030*
Left masseter at rest (microV)	1.48	3.48	2.35	2.30	13.18	.060*
Left anterior temporalis at function (microV)	148.98	171.22	185.11	170.89	21.01	.005*
Left masseter at function (microV)	161.13	175.06	177.60	177.26	6.28	.001*
Activity index	5.75	4.70	5.14	4.93	2.58	.040*
Asymmetry index	5.11	6.65	5.48	5.05	6.66	.001*
BioJVA variables						
Total integral energy right TMJ	56.20	84.60	81.06	81.53	7.52	.0003*
Total integral energy left TMJ	61.13	87.73	75.86	85.84	10.63	.001*
>300/<300 ratio right TMJ	0.18	0.15	0.31	0.21	23.29	.0001*
>300/<300 ratio left TMJ	0.17	0.14	0.33	0.21	53.46	.0008*
Peak amplitude	24.51	22.16	29.44	25.08	11.30	.001*
Peak frequency	71.13	63.13	74.00	64.84	5.38	.002*
JT3D variables						
Maximum vertical mouth opening (mm)	45.33	44.66	39.86	41.46	2.87	.060*
Maximum sagittal movement (mm)	5.66	6.10	4.80	4.87	5.92	.001*
Lateral left (mm)	3.96	3.55	3.24	2.75	6.89	.0004*
Lateral right (mm)	4.29	4.86	2.88	3.13	30.38	.001*

contraction, and of the anterior temporalis during rest position, in TMD-affected patients. The present study showed that muscular improvement in Group II and control was negligible in comparison to significant improvement in Group I and III, indicating that the muscular response observed in Group II orthodontic-alone patients was as good as no treatment. We also observed that orthodontic treatment combined with occlusal splint therapy resulted in significant improvement in muscular health than without splint orthodontic treatment. A few control group participants reported mild worsening of muscular health, which indicate that unequal activity of the right and left side muscle movement and antagonist muscle activity might occur if no treatment is provided. However, the reported improvement with orthodontic treatment in the healthy patient group, and the results of orthodontics in conjunction with occlusal splint therapy in the TMDs group support the findings of Miralles et al.[42] who also reported greater improvement in masseter and temporalis muscles in healthy subjects than in non-healthy subjects with right-side dominance while clenching. The present study contradicts the findings of Wieczorek and Loster[43] who observed no significant differences in occlusal contact, asymmetry, or activity indexes among healthy orthodontically treated or untreated young adults. However, the authors reported significant difference between females and males, with a higher activity index in females. The present study did not assess the gender and malocclusion-wise differentiation in any of the parameters involved with TMD due to limited sample size in sub-variable categories. Ferrario et al.[44] reported the predominance of right-side involvement in their study, stating predominantly a right-handed general population; however, our study did not corroborate a similar finding. The difference could be due to the mixed sample size of the present study.

Table 7. Comparison of posttreatment measurements between different groups by ANOVA test

Assessment Variables	Mean at T_1				ANOVA test	
'T' scan variables	Group I	Group II	Group III	Group IV	*F* value	*P*
Maximum bite force right side (%)	51.13	51.06	50.66	47.30	1.33	.270
Maximum bite force left side (%)	48.86	49.06	49.33	52.69	1.30	.280
Difference between right and left	3.066	4.13	4.26	20.46	9.50	.0001*
Maximum bite force anterior region (%)	7.26	6.80	5.60	15.53	15.77	.001*
Maximum bite force posterior region (%)	93.00	93.20	94.06	93.00	0.66	.578
Right lateral excursive DT (seconds)	0.33	0.22	0.38	0.64	9.97	.0001*
Left lateral excursive DT (seconds)	0.28	0.23	0.37	0.7	21.12	.001*
BioEMG variables						
Right anterior temporalis at rest (microV)	0.52	2.48	0.65	1.2	40.95	.001*
Right masseter at rest (microV)	0.58	2.84	0.87	3.43	49.78	.0001*
Right anterior temporalis at function (microV)	117.73	158.92	128.45	170.85	31.22	.001*
Right masseter at function (microV)	134.32	181.31	135.95	186.96	36.83	.060
Left anterior temporalis at rest (microV)	0.73	3.040	1.006	1.94	32.13	.080
Left masseter at rest (microV)	1.01	3.060	0.79	2.20	33.34	.001*
Left anterior temporalis at function (microV)	123.13	171.04	140.99	172.36	58.95	.003*
Left masseter at function (microV)	130.92	178.26	175.67	179.48	35.44	.001*
Activity index	4.48	5.14	2.73	4.97	23.77	.001*
Asymmetry index	3.72	6.98	3.42	5.25	29.50	.010*
BioJVA variables						
Total integral energy right TMJ	45.46	81.33	43.60	87.69	22.51	.006*
Total integral energy left TMJ	48.93	85.46	40.80	91.00	37.61	.004*
>300/<300 ratio right TMJ	0.16	0.14	0.18	0.25	10.50	.0001*
>300/<300 ratio left TMJ	0.16	0.14	0.19	0.25	16.09	.001*
Peak Amplitude	21.45	24.12	17.34	27.91	25.34	.001
Peak Frequency	64.66	60.66	37.33	67.84	42.31	.003
JT3D variables						
Maximum vertical mouth opening (mm)	46.40	44.86	47.20	42.92	1.76	.160
Maximum sagittal movement (mm)	5.63	6.17	5.53	4.98	3.68	.017*
Lateral left (mm)	4.10	3.78	3.92	2.83	7.87	.0002*
Lateral right (mm)	4.49	4.90	3.74	3.21	22.01	.001*

Healthy human joints produce little noise. Subsequent surface changes due to TMD can cause increased friction and vibration. It has also been reported that different disorders produce different vibration patterns. The present study utilized the joint vibrations and jaw trackers simultaneously to locate and compare the signs and symptoms of TMD such as click, crepitus or pop, limited mouth opening, and jaw deviation. The BioJVA is based on the electro vibratography concept with 70%–85% sensitivity and specificity as reported by various investigators.[45,46] Durrani et al.[47] and Devi et al.[24] have reported significant reliability of BioJVA in the healthy Indian population and TMD-affected patients, respectively. The present study found significant difference in TMJ vibration, with greater improvement in Group I, compared to Group II which did not show any significant improvements in most of the variables after orthodontic treatment. Group III patients showed improvement in all variables after treatment. The control group showed deterioration of most of the variables related to TMJ vibration. Thus, the present study infers that that merely orthodontic alignment of teeth may not improve the signs and symptoms of TMD-affected patients, unless preceded by splint therapy.

Orthodontic treatment of patients with TMDs often presents a complex clinical challenge due to muscle incoordination, bony alterations, and the patient's unstable condylar position, all of which together cause the occlusion to change constantly during treatment.[29] Stabilization of the TMJ structures by splint therapy is necessitated in such patients to identify and maintain the true mandibular position and predict patients' response before institution of orthodontic mechanotherapy.[48] Among the 3 splint designs, namely, the anterior repositioning appliance (ARA), the CSS, and the soft splint, correct choice of the splint design is often a unique challenge for a clinician.[24] In accordance with the recommendations of Chang et al.[49]

who reported fewer problems with CSS in comparison to ARA after treatment, we used CSS for a period varying from 12 weeks to 24 weeks depending on severity of pretreatment TMJ symptoms. The findings of this study, showing significant improvement in TMJ symptoms after splint therapy, further corroborated those of previous reports, which showed that splint therapy helps restore a novel functional equilibrium in the stomatognathic system by permitting smoother condylar translation beyond disc surface inhomogeneity and reducing joint noises by increasing the joint space. Additionally, numerous studies have also demonstrated improvement of clinical symptoms during orthodontic treatment by virtue of therapeutic effects of the splint and elimination of the impact of occlusal interferences, thereby allowing for physiologic-seated condylar position and optimizing final treatment results by attaining maximum intercuspation-seated condylar position coincidence.[48,50-52]

The findings of this study, showing improvement in all variables of mandibular movement in the splint orthodontic group in comparison to the other 3 groups, further indicate that orthodontics play a limited role in management of TMD in orthodontic patients. Similar findings have also been reported by Imai et al.[50] who also found significant beneficial effects of combination of splint therapy and orthodontic treatment in reducing pain and restriction of mandibular movement. This study demonstrated substantial improvement in relation to muscular and occlusal parameters in the healthy group in comparison to the TMD group. In accordance with the findings of StieschScholz et al.[46] and Suvinen and Reade,[53] the significant improvement observed in Group III could be attributed to disclusion of posterior teeth and relaxation of elevator muscles owing to condylar guidance in all movements, which helps maintain jaw position and contributes to decreased muscle hyperactivity and subsequent TMD symptoms.

It has been consistently reported that realization of the goals of optimal occlusion, functional stability in masticatory structures, muscle equilibration, and an orthopedically stable relationship between the occlusal position of the teeth and the joint position with orthodontic treatment might play an important role in preventing or diminishing the risk factors associated with development of TMDs.[14,54]

To the best of our knowledge, the present study is first of its kind to rule out the suspected role of orthodontics in the etiopathogenesis of TMD using biometric assessment. The major advantages of these biometric equipment were digital documentation, repeatable measurement, and non-radiating and quantitative assessment of TMD signs and symptoms. However, the present study recommends the hands-on experience of these devices before accurate interpretation and reporting. The finding of present study rejected the null hypothesis, partially as there was no precipitation or aggravation of TMD signs and symptoms, and definite symptomatic improvement and relief after comprehensive orthodontic treatment in tandem with splint therapy was obtained.

Our study could not report the different demographic-based biometric data such as different malocclusions, gender, and age group, due to paucity of samples and resources; hence demonstrating limited generalizability and external validity. However, the issue can be addressed with multicentric trials involving a larger sample size in different populations and over a longer observation period.

CONCLUSION

This study reported the successful role of biometric assessment equipment in orthodontic patients. Based on the results of this randomized control trial, the following can be concluded:

- Comprehensive fixed orthodontic treatment does not aggravate TMDs.
- TMDs attributable to unstable orthodontic malocclusion can be treated successfully with comprehensive orthodontic treatment.
- TMDs due to multifactorial TMJ and muscular component are less likely to benefit with orthodontic treatment alone and usually require splint therapy at least for 3 months.

Ethics Committee Approval: 'Institutional Ethical Committee' approval vide letter number 14/IEC/ADCRR/2017.

Informed Consent: Informed consent was obtained from the all patients.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - R.K.M.; Design - R.K.M.; Supervision - H.S.; Materials - R.K.M., H.S.; Data Collection and/or Processing - R.K.M.; Analysis and/or Interpretation - R.K.M., H.S., B.T.; Literature Review - H.S., P.S., P.K.; Writing - R.K.M., H.S., B.T., P.S., P.K.; Critical Review - B.T., P.S., P.K.

Acknowledgments: The authors acknowledge the support of all patients and staff & M/s Villa India for support of BioEMG , BioJVA and Jaw Tracker.

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

Funding: The authors declared that this study has received no financial support.

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Table S1. Results of Tukey HSD posthoc Test showing the intergroup levels of significance at T0 and T1 for parameters of Digital Occlusal Analysis

	Group I		Group II		Group III		Group IV	
	T0	T1	T0	T1	T0	T1	T0	T1
1	**Difference between right and left biting Force**							
Group I	-	-	0.56	0.87	0.08	0.6	0.65	**0.0001**
Group II	0.56	0.87	--	--	0.45	0.09	0.76	**0.0001**
Group III	0.08	0.6	0.45	0.09	--	--	0.98	**0.0001**
2	**Maximum Bite force anterior region (%)**							
Group I	--	--	0.34	0.67	0.08	0.10	0.094	**0.0001**
Group II	0.34	0.67	--	--	0.88	0.45	**0.002**	**0.0001**
Group III	0.08	0.10	0.88	0.45	--	--	0.06	**0.0001**
3	**Maximum Bite Force Posterior region (%)**							
Group I	--	--	0.50	0.65	1.3	0.90	0.32	0.45
Group II	0.50	0.65	--	--	0.78	0.92	**0.034**	0.66
Group III	1.3	0.90	0.78	0.92	--	--	0.23	0.80
4	**Right Lateral excursive DT (seconds)**							
Group I	--	--	0.54	0.79	0.12	0.09	0.10	**0.002**
Group II	0.54	0.79	--	--	0.80	0.34	**0.0005**	**0.0001**
Group III	0.12	0.09	0.80	0.34	--	--	0.09	**0.012**
5	**Left Lateral excursive DT (seconds)**							
Group I	--	--	**0.016**	0.20	0.89	0.23	0.50	**0.0001**
Group II	**0.016**	0.20	--	--	**0.011**	0.56	**0.025**	**0.0001**
Group III	0.89	0.23	**0.011**	0.56	--	--	0.78	**0.0001**

Table S2. Results of Tukey HSD posthoc Test showing the intergroup levels of significance at T0 and T1 for parameters of Digital Muscular activity using EMG

	Group I		Group II		Group III		Group IV	
	T0	T1	T0	T1	T0	T1	T0	T1
1	**Right Anterior Temporalis at rest (microV)**							
Group I	--	--	**0.0001**	**0.0001**	0.44	0.65	0.87	**0.006**
Group II	**0.0001**	**0.0001**	--	--	**0.0001**	**0.0001**	**0.0001**	**0.0001**
Group III	0.44	0.65	**0.0001**	**0.0001**	--	--	0.08	0.034
2	**Right Masseter at rest (microV)**							
Group I	--	--	**0.0001**	**0.0001**	**0.0001**	0.60	0.20	**0.0001**
Group II	**0.0001**	**0.0001**	--	--	0.56	**0.0001**	**0.0001**	0.32
Group III	**0.0001**	0.60	0.56	**0.0001**	--	--	0.09	**0.0001**
3	**Right Anterior Temporalis at function (microV)**							
Group I	--	--	**0.036**	**0.0001**	**0.0001**	0.80	**0.0003**	**0.0001**
Group II	**0.036**	**0.0001**	--	--	0.55	**0.0001**	**0.010**	0.08
Group III	**0.0001**	0.80	0.55	**0.0001**	--	--	0.07	**0.0001**
4	**Right Masseter at function (microV)**							
Group I	--	--	**0.004**	**0.0001**	**0.0001**	0.98	**0.0001**	**0.0001**
Group II	**0.004**	**0.0001**	--	--	0.06	**0.0001**	0.79	0.98
Group III	**0.0001**	0.98	0.06	**0.0001**	--	--	0.90	**0.0001**
5	**Left Anterior Temporalis at rest (microV)**							
Group I	--	--	**0.0001**	**0.0001**	**0.001**	0.78	**0.04**	**0.0003**
Group II	**0.0001**	**0.0001**	--	--	**0.001**	**0.0001**	**0.0001**	**0.001**
Group III	**0.001**	0.78	**0.001**	**0.0001**	--	--	0.06	**0.005**
6	**Left Masseter at rest (microV)**							
Group I	--	--	**0.0001**	**0.0001**	**0.042**	0.07	**0.04**	**0.0004**
Group II	**0.0001**	**0.0001**	--	--	**0.004**	**0.0001**	**0.004**	**0.011**
Group III	**0.042**	0.07	**0.004**	**0.0001**	--	--	0.09	**0.0001**
7	**Left Anterior Temporalis at function (microV)**							
Group I	--	--	**0.0002**	**0.0001**	**0.0001**	**0.00009**	**0.0003**	**0.0001**
Group II	**0.0002**	**0.0001**	--	--	**0.019**	**0.0001**	**0.004**	**0.011**
Group III	**0.0001**	**0.00009**	**0.019**	**0.0001**	--	--	**0.022**	**0.0001**
8	**Left Masseter at function (microV)**							
Group I	--	--	**0.012**	**0.0001**	**0.002**	**0.0001**	**0.004**	**0.0001**
Group II	**0.012**	**0.0001**	--	--	0.07	**0.0001**	0.40	**0.011**
Group III	**0.002**	**0.0001**	**0.004**	**0.0001**	--	--	0.60	**0.0001**
9	**Activity Index**							
Group I	--	--	**0.048**	**0.0001**	0.80	**0.0001**	0.56	0.009
Group II	**0.048**	**0.0001**	--	--	0.70	**0.0001**	0.45	0.55
Group III	0.80	**0.0001**	0.70	**0.0001**	--	--	0.89	**0.0001**
10	**Asymmetry index**							
Group I	--	--	**0.004**	**0.0001**	0.90	**0.0001**	0.80	**0.005**
Group II	**0.004**	**0.0001**	--	--	**0.014**	**0.0001**	**0.006**	**0.001**
Group III	0.90	**0.0001**	**0.014**	**0.0001**	--	--	0.30	**0.0007**

Table S3. Results of Tukey HSD posthoc Test showing the intergroup levels of significance at T0 and T1 for parameters of TMJ vibration analysis

	Group I		Group II		Group III		Group IV	
	T0	T1	T0	T1	T0	T1	T0	T1
1	**Total Integral energy right TMJ**							
Group I	--	--	**0.0007**	**0.0001**	**0.003**	0.08	**0.003**	**0.0001**
Group II	**0.0007**	**0.0001**	--	--	0.50	**0.0001**	0.60	0.65
Group III	**0.003**	0.08	0.50	**0.0001**	--	--	0.30	**0.0001**
2	**Total Integral energy Left TMJ**							
Group I	--	--	**0.0001**	**0.0001**	**0.033**	0.08	**0.0003**	**0.0001**
Group II	**0.0001**	**0.0001**	--	--	0.80	**0.0001**	0.45	0.90
Group III	**0.033**	0.08	0.80	**0.0001**	--	--	0.09	**0.0001**
3	**>300/<300 ratio Right TMJ**							
Group I	--	--	0.08	0.09	**0.0001**	0.50	**0.0003**	**0.0005**
Group II	0.08	0.09	--	--	**0.0001**	0.12	**0.023**	**0.0001**
Group III	**0.0001**	0.50	**0.0001**	0.12	--	--	**0.0002**	**0.013**
4	**>300/<300 ratio Left TMJ**							
Group I	--	--	0.08	0.07	0.80	0.40	0.70	**0.0001**
Group II	0.08	0.07	--	--	**0.034**	0.70	**0.0008**	**0.0001**
Group III	0.80	0.40	**0.034**	0.70	--	--	**0.0001**	**0.001**
5	**Peak Amplitude**							
Group I	--	--	0.90	0.40	**0.001**	**0.007**	0.70	**0.0001**
Group II	0.90	0.40	--	--	**0.0001**	**0.0001**	0.06	**0.019**
Group III	**0.001**	**0.007**	**0.0001**	**0.0001**	--	--	**0.009**	**0.0001**
6	**Peak Frequency**							
Group I	--	--	0.67	0.80	0.45	**0.0001**	0.70	0.23
Group II	0.67	0.80	--	--	**0.005**	**0.0001**	0.50	0.45
Group III	0.45	**0.0001**	**0.005**	**0.0001**	--	--	**0.030**	**0.0001**

Table S4. Results of Tukey HSD posthoc Test showing the intergroup levels of significance at T0 and T1 for parameters of Mandibular Movement Analysis

	Group 1		Group 2		Group 3		Group 4	
	T0	**T1**	**T0**	**T1**	**T0**	**T1**	**T0**	**T1**
1	**Maximum sagittal movement (mm)**							
Group I	--	--	0.80	0.56	0.06	0.08	0.60	0.09
Group II	0.80	0.56	--	--	**0.003**	**0.34**	**0.009**	**0.008**
Group III	0.06	0.08	**0.003**	**0.34**	--	--	0.90	0.50
2	**Lateral left (mm)**							
Group I	--	--	0.70	0.32	**0.02**	0.80	**0.008**	**0.0001**
Group II	0.70	0.32	--	--	0.60	0.70	**0.046**	**0.007**
Group III	**0.02**	0.80	0.60	0.70	--	--	0.09	**0.001**
3	**Lateral Right (mm)**							
Group I	--	--	0.09	0.07	**0.0001**	**0.006**	**0.0002**	**0.0001**
Group II	0.09	0.07	--	--	**0.0001**	**0.0001**	**0.0001**	**0.0001**
Group III	**0.0001**	**0.006**	**0.0001**	**0.0001**	--	--	0.70	0.08

TURKISH JOURNAL of ORTHODONTICS

DOI: 10.5152/TurkJOrthod.2022.21169

Systematic Review

Vacuum-Formed Retainers Versus Lingual-Bonded Retainers: A Systematic Review and Meta-Analysis of Stability of Treatment Outcomes in Orthodontically Treated Patients

Seerab Husain, Shantha Sundari, Ravindra Kumar Jain, Arthi Balasubramaniam

Department of Orthodontics and Dentofacial Orthopaedics, Saveetha Dental College and Hospital, Chennai, Tamilnadu, India

Cite this article as: Husain S, Sundari S, Jain RK, Balasubramaniam A. Vacuum-formed retainers versus lingual-bonded retainers: A systematic review and meta-analysis of stability of treatment outcomes in orthodontically treated patients. *Turk J Orthod.* 2022;35(4):307-320.

Main Points

- A very low level of evidence suggests that both vacuum-formed retainers (VFRs) and lingual-bonded retainers (LBRs) are equally effective in maintaining treatment stability.
- A moderate level of evidence suggests that periodontal status was similar in both retainers.
- A moderate level of evidence suggests that there was no difference in the retainer failure rates of VFRs and LBRs.
- A moderate level of evidence suggests that VFRs were associated with speech difficulty, discomfort, and soreness in the lower arch than LBRs during baseline and 18 months follow-up time period, and they were better than LBRs in maintaining oral hygiene.

ABSTRACT

Objective: This review aimed at analyzing the literature comparing vacuum-formed retainers and lingual-bonded retainers for maintaining treatment stability and periodontal health and evaluating retainer failure and patient satisfaction.

Methods: Electronic databases such as PubMed, Cochrane Library, Ovid, Scopus, Web of Science, and Google Scholar were searched. Only randomized controlled trials were involved. Risk of bias was evaluated using Risk of Bias 2 Tool. Meta-analysis was performed and certainty of evidence was assessed with Grading of Recommendations Assessment, Development, and Evaluation approach.

Results: Five randomized controlled trials were included for qualitative analysis and 2 studies were included for quantitative analysis. Two studies concluded that lingual-bonded retainers were more effective than vacuum-formed retainers in maintaining treatment stability. Two studies had a high risk of bias and 3 studies had some concerns. No statistically significant difference in Little's Irregularity Index (standard mean difference = −0.10; *P* value = .61), inter-canine width (standard mean difference = 0.66; *P* value = .09), inter-molar width (standard mean difference = 0.08; *P* value = .85), arch length (standard mean difference = −0.18; *P* value = .60) between the 2 retainers was noted. Periodontal status and retainer failure rate (odds ratio= 2.28; *P* value = .23) were similar in both retainers. Patient discomfort, soreness, and speech difficulty were more with vacuum-formed retainers and oral hygiene maintenance was easier with vacuum-formed retainers.

Conclusion: A very low-level certainty of evidence suggests that both vacuum-formed retainers and lingual-bonded retainers were equally effective in maintaining treatment stability. Periodontal status and retainer failures were similar in both retainers. Vacuum-formed retainers were better for oral hygiene maintenance but were associated with discomfort, soreness, and speech difficulty than lingual-bonded retainers.

Keywords: Orthodontic retainer, periodontal, relapse, retention, stability, survival rate

INTRODUCTION

Orthodontic treatment is considered complete and successful as long as it is followed by an ideal retention protocol. The dentition is under the constant influence of mechanical forces from surrounding structures like tongue,

Corresponding author: Seerab Husain, e-mail: serab7421@gmail.com

Received: August 13, 2021
Accepted: January 24, 2022
Publication Date: December 30, 2022

Turk J Orthod 2022; 35(4): 307-320

cheeks, and lips. Furthermore, the microstructures around the teeth such as the periodontium and the alveolar bone also require adequate time to mature and adapt to their new position.[1] Until such time, it becomes crucial for the orthodontist to resort to means, which would facilitate holding the dentition passively in the newly moved position, just long enough for the surrounding dental tissues to readapt.

Retention appliances can be broadly classified into 2 categories, such as removable retainers (Hawley's retainer, Begg's wraparound retainer, vacuum-formed retainers (VFRs), and tooth positioners) and fixed retainers (lingual-bonded retainers (LBRs)).[2] The choice of retention appliance used not only depends on the clinical requirement of the patient but also relies heavily on the patients' compliance.[3] Vacuum-formed retainers or thermoplastic retainers are popular among dentists, and patient's acceptance is more when compared with Hawley's appliance (HA) due to their superior aesthetics, comfort, and lesser incidences of breakage.[4,5] Several studies comparing the effectiveness of HA with VFRs have shown that VFRs are more effective in retaining treatment results.[3,5-9] As far as fixed retainers are concerned, LBRs are the most commonly preferred type of retainers by orthodontists and patients alike.[10] Multistrand braided coaxial wires are most often the preferred material of choice for LBR fabrication, which are bonded with the help of flowable unfilled composite.[11] The relatively smaller dimension of the wire makes it almost unnoticeable intraorally, favoring patient compliance. However, this is also the reason why most of the LBR failures go unnoticed, leading to relapse.[2]

Good periodontal health also plays a crucial role in maintaining the treatment outcomes of fixed orthodontic therapy. Microbial flora is considered to be one of the important causative factors of periodontal disease.[12] Several studies have shown that plaque accumulation is more around fixed retainers that serve as a reservoir for microbial flora predisposing the teeth to periodontal problems.[13-15]

Previous systematic reviews by Littlewood et al.[16], Al-Moghrabi et al.[17], Westerlund et al.[18] and Iliadi et al.[19] have compared removable and fixed retainers for treatment stability but were inconclusive owing to the lack of high-quality evidence. The present review specifically addresses the differences between VFRs and LBRs as there is no other previously published systematic review comparing these 2 retainers. Hence, the aim of this systematic review was to analyze the available literature on the comparison of orthodontic treatment stability, periodontal status, patient satisfaction, and failure rate of retainers between patients receiving VFRs and LBRs.

METHODS

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. The review protocol was registered with the PROSPERO database (CRD42020215047).

The selection of articles for this systematic review was done based on the criteria mentioned in Table 1.

Search Strategy Employed for Study Identification

Detailed search strategies were developed and appropriately revised for each database, considering the differences in controlled vocabulary and syntax rules. The following electronic databases were searched individually by 3 authors (S.H., S.S., and R.K.J.): MEDLINE (via Ovid and PubMed, from 1946 to May 30, 2021), Google Scholar, the Cochrane Oral Health Group's Trials Register, SCOPUS, and Web of Science (Table 2).

Unpublished literature was searched on ClinicalTrials.gov, the National Research Register, and Pro-Quest Dissertation Abstracts and Thesis database. The search attempted to identify all relevant studies irrespective of language. The reference lists of all eligible studies were hand-searched for additional studies. Articles were screened for duplicates using EndNote Software (Version X9; Clarivate Analytics, Philadelphia, Pa, USA).

Eligibility and Screening of Retrieved Papers

A study was judged eligible when it included 2 treatment arms—retention using VFR and LBR and none of the exclusion criteria were fulfilled. After the removal of duplicates,

Table 1. Eligibility criteria for study selection

Category	Inclusion Criteria	Exclusion Criteria
Participants	Studies reporting on the subjects treated with retainers in maxillary/mandibular arch after fixed orthodontic treatment, irrespective of age, gender, and malocclusion	
Intervention	Vacuum-formed retainers, Essix retainers, pressure-formed retainers, thermoplastic retainers	Other removable retainers
Comparison	Fixed lingual retainer, lingual-bonded retainer	Other retainers or no comparison group
Outcomes	Primary outcome: treatment stability as assessed by parameters such as Little's Irregularity Index, arch width, and length changes Secondary outcome: periodontal status, the failure rate of retainers, and patient satisfaction	
Study design	Randomized clinical trials (RCTs)	Split-mouth RCTs Retrospective studies Case reports Comments, letters to the editor Narrative reviews Laboratory studies

Table 2. Search strategy table

Databases	Keywords/Mesh Terms	Total Count
PubMed	(((((((((((orthodontic fixed lingual retainer) OR (orthodontic bonded retainer)) OR (lingual retainer)) AND (orthodontic vacuum formed retainer)) OR (orthodontic clear retainer)) OR (essix retainer)) OR (thermoplastic retainer)) AND (orthodontic stability)) OR (incisor crowding)) OR (post treatment stability)) AND (randomizedcontrolledtrial[Filter]))	1031
Ovid	(vacuum formed retainer OR essix retainer OR thermoplastic retainer) AND (bonded retainer OR lingual bonded retainer OR fixed lingual retainer).af.	78
Google Scholar	vacuum formed retainer AND thermoplastic retainer AND essix retainer AND bonded retainer AND fixed lingual retainer AND orthodontic stability AND orthodontic retention	139
Cochrane Library	(vacuum formed retainer):ti,ab,kw OR (clear retainer):ti,ab,kw OR (thermoplastic retainer):ti,ab,kw AND (orthodontic retainer):ti,ab,kw AND (bonded retainer):ti,ab,kw	62
SCOPUS	(vacuum formed retainer OR thermoplastic retainer OR essix retainer) AND (bonded retainer OR fixed lingual retainer) AND (orthodontic stability) AND (orthodontic retention)	65
Web of Science	((((((ALL=(vacuum formed retainer)) OR ALL=(thermoplastic retainer)) OR ALL=(essix retainer)) AND ALL=(lingual bonded retainer)) OR ALL=(fixed lingual retainer)) AND ALL=(orthodontic stability)) AND ALL=(orthodontic retention)	29

articles were screened on the basis of title and abstract. Full-text reading of the screened studies was carried out to finalize the included studies for the review. The sequential selection of studies for the review is represented in the PRISMA flow diagram (Figure 1).

Qualitative Assessment

The Cochrane Collaboration's Risk of Bias 2 tool was used for qualitative assessment in the following domains: randomization process, deviation from intended intervention, missing outcome data, measurement of the outcome, and selection of reported

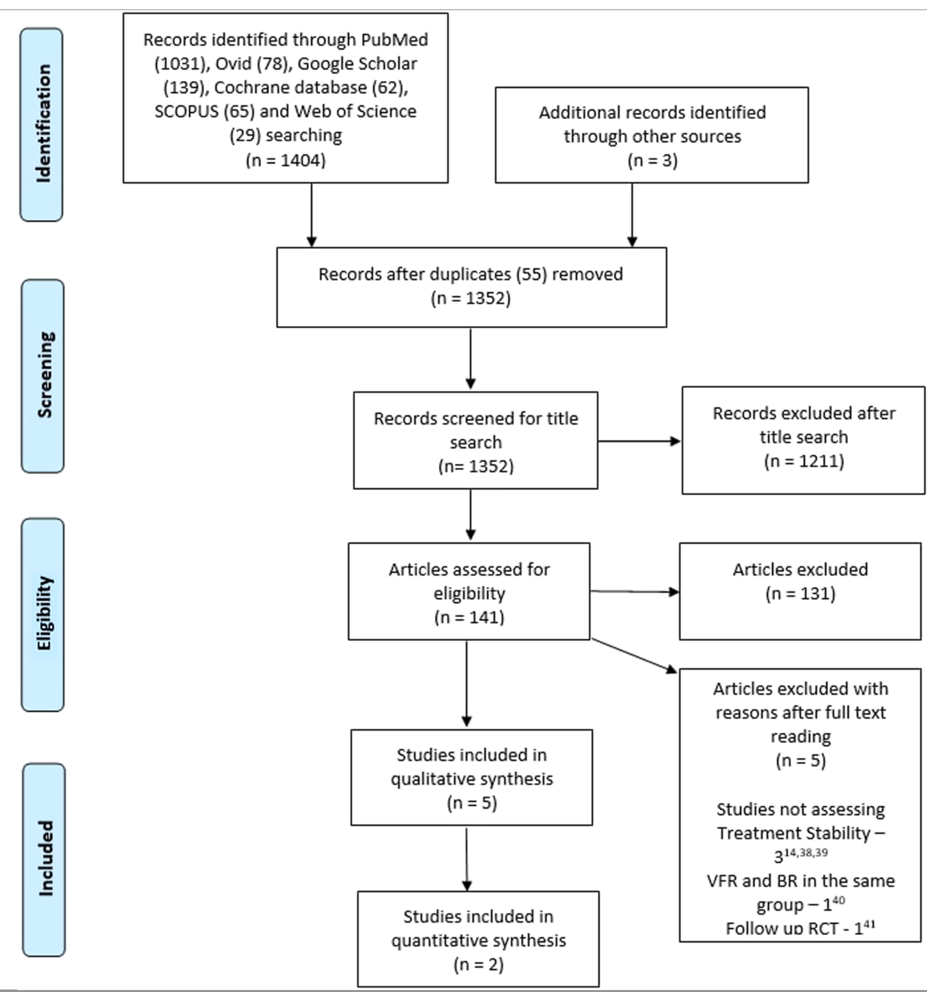

Figure 1. Preferred reporting items for systematic reviews and meta-analyses flow diagram of included studies

results. Risk of bias assessment was done individually by 3 authors (S.H., S.S., and R.K.J.). Disagreements were resolved by a joint discussion with the fourth author (A.B.). The authors of the included studies were contacted for clarification if required. Certainty of evidence was assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach for their study design, risk of bias, inconsistency, indirectness, imprecision, and publication bias.[20]

Analysis of Data

A narrative description of the findings of all the included studies was provided, aiming at the stability of the treatment, periodontal status, patient perception, and failure rate of retainers. Meta-analysis of the primary outcome was performed using RevMan Web, and standard mean differences were computed. A subgroup analysis was performed for the outcome parameters evaluating the treatment stability (Little's Irregularity Index (LII), inter-canine width (ICW), inter-molar width (IMW), arch length (AL), overjet (OJ), and overbite (OB)). Similarly, meta-analysis for the secondary outcome (retainer failure) was performed using odds ratio. Publication bias analysis was also performed. Statistical heterogeneity was represented graphically by displaying estimated treatment effects from the included trials with 95% CIs. I^2 was used to quantify heterogeneity with values more than 50% indicating moderate to high heterogeneity. Fixed effects model was employed if the heterogeneity (I^2) < 40%, and random effect model was employed if the heterogeneity (I^2) > 40%.

RESULTS

Description of Included Studies

The sequential selection of studies for the review is represented in the PRISMA flow diagram (Figure 1). A total of 1404 records were identified after the preliminary search of 6 databases, and 3 records were obtained from the manual search. After removal of duplicates and application of inclusion and exclusion criteria, 10 articles were subjected to full-text reading and 5 were excluded with reasons[14,38-41] (Appendix 1). A total of 5 studies were included in this systematic review for qualitative analysis, and meta-analysis of the primary outcome and secondary outcome (retainer failure) was performed for 2 of the included studies (Figures 2 and 3). Two additional articles were included in this review for qualitative assessment since they were a continuation of the included studies.[21,22] The characteristics of participants, comparison groups, follow-up period, and the outcomes of the included studies are presented in Table 3.

A total of 396 participants were involved across the 5 selected studies, out of which 173 were males and 223 were females. All included studies had reported on changes in LII, AL, ICW, and IMW of either arch for treatment stability. Overjet and OB were evaluated in 3 of the 5 included studies,[24-27] whereas 1 study additionally evaluated extraction space opening.[23] Two of the 5 included studies reported on the plaque index (PI) and gingival index (GI),[22,25] whereas 1 study reported on calculus index (CI),[22] bleeding on probing (BOP), and pocket depth (PD).[25] Retainer failure was reported in 2 of the 5 studies.[24,27] Patient satisfaction was evaluated in 2 of the 5 included studies.[21,27] Three of the 5 included studies had evaluated the review outcomes only in the mandibular arch,[23-25] 1 study had evaluated the review outcomes in the maxillary arch,[26] and 1 study had evaluated in both maxillary and mandibular arches.[27] Different follow-up periods and retainer wear protocols were followed in each of the included studies, as depicted in Table 3. Measurements of treatment stability outcomes were performed using manual study cast and digital caliper in 1 study,[23] scanned digital model and different digital software in the rest of the studies.[24-27] Only 2 of the 5 included studies had reported about the inclusion of extraction as well as non-extraction cases, but the percentage of patients who underwent extraction was not reported by both the studies.[24,27] Three of the 5 studies[24-26] had excluded patients who underwent orthognathic surgery and 1 study had excluded patients who underwent maxillary expansion.[24]

Risk of Bias/Methodological Quality Assessment of Included Studies

Out of the 5 randomized controlled trials included for this review, 2 were deemed to have a high risk of bias,[23,27] whereas the 3 other studies were adjourned to have some concerns for the risk of bias assessment[24-26] (Figures 4 and 5).

None of the included studies reported blinding of operator and patient since it was not possible due to the nature of the intervention being delivered. Blinding of the outcome assessor was done only in 3 of the 5 included studies.[23,25,26] Intention to treat analysis was done in 3 out of the 5 included studies to address the missing outcome data.[24,26,27]

A high risk of bias was given for the trial by O'Rourke et al.[23] for the domain assessing bias due to deviation from intended intervention, whereas the other 4 trials had some concerns in this domain. Studies by Forde et al.[27] and Krämer et al.[24] had some concerns in the domain assessing the measurements of the outcomes as these 2 studies reported partial or no blinding of the outcome assessor. Studies by O'Rourke et al.[23], Forde et al.[27] and Alrawas et al.[25] presented some concerns in the domain assessing the selection of the reported studies as these studies were not pre-registered and there was no information indicating any deviation from the pre-specified plan.

TREATMENT STABILITY

The data for the treatment stability in 2 of the included studies were mentioned as median and interquartile range,[24,27] in 1 study, the same was mentioned in terms of the difference between the median and interquartile range between appointments,[23] and in the studies by Naraghi et al.[26] and Alrawas et al.[25] mean and standard deviations (SDs) were performed for assessing the outcome parameters.

Little's Irregularity Index

Two studies reported increased LII scores for VFRs which were statistically significant at the 6-month time interval in 1 study[23] and at 3 and 12 months in another study.[27] The other 3 studies, however, reported no statistically significant difference in LII scores

Study or Subgroup	LBR Mean	LBR SD	LBR Total	VFR Mean	VFR SD	VFR Total	Weight	Std. mean difference IV, Random, 95% CI
1.1.1 LII								
Forde et al	1.01	1.28	30	1.73	2.77	30	7.7%	-0.33 [-0.84 , 0.18]
Kramer et al	1.91	1.11	52	1.83	1.45	52	9.1%	0.06 [-0.32 , 0.45]
Subtotal (95% CI)			**82**			**82**	**16.8%**	**-0.10 [-0.47 , 0.28]**
Heterogeneity: Tau² = 0.02; Chi² = 1.44, df = 1 (P = 0.23); I² = 31%								
Test for overall effect: Z = 0.50 (P = 0.61)								
1.1.2 Inter-canine width								
Forde et al	28.06	1.65	30	26.26	1.65	30	7.3%	1.08 [0.53 , 1.62]
Kramer et al	27.25	2.34	52	26.58	2.13	52	9.0%	0.30 [-0.09 , 0.68]
Subtotal (95% CI)			**82**			**82**	**16.4%**	**0.66 [-0.10 , 1.42]**
Heterogeneity: Tau² = 0.25; Chi² = 5.24, df = 1 (P = 0.02); I² = 81%								
Test for overall effect: Z = 1.70 (P = 0.09)								
1.1.3 Inter-molar width								
Forde et al	44.23	2.34	30	41.84	6.22	30	7.6%	0.50 [-0.01 , 1.02]
Kramer et al	42.38	3.25	52	43.46	3.68	52	9.0%	-0.31 [-0.70 , 0.08]
Subtotal (95% CI)			**82**			**82**	**16.7%**	**0.08 [-0.72 , 0.87]**
Heterogeneity: Tau² = 0.27; Chi² = 6.10, df = 1 (P = 0.01); I² = 84%								
Test for overall effect: Z = 0.19 (P = 0.85)								
1.1.4 Arch length								
Forde et al	67.06	8.83	30	65.17	11.42	30	7.7%	0.18 [-0.32 , 0.69]
Kramer et al	54.1	8.09	52	58.59	9.92	52	9.0%	-0.49 [-0.88 , -0.10]
Subtotal (95% CI)			**82**			**82**	**16.7%**	**-0.18 [-0.84 , 0.49]**
Heterogeneity: Tau² = 0.17; Chi² = 4.27, df = 1 (P = 0.04); I² = 77%								
Test for overall effect: Z = 0.52 (P = 0.60)								
1.1.5 Overbite								
Forde et al	1.52	0.92	30	1.92	0.97	30	7.7%	-0.42 [-0.93 , 0.09]
Kramer et al	2.13	1.46	52	1.93	1.51	52	9.1%	0.13 [-0.25 , 0.52]
Subtotal (95% CI)			**82**			**82**	**16.7%**	**-0.12 [-0.65 , 0.42]**
Heterogeneity: Tau² = 0.10; Chi² = 2.85, df = 1 (P = 0.09); I² = 65%								
Test for overall effect: Z = 0.42 (P = 0.67)								
1.1.6 Overjet								
Forde et al	2.53	1.09	30	2.74	0.5	30	7.7%	-0.24 [-0.75 , 0.26]
Kramer et al	2.98	1.27	52	3.43	1.41	52	9.0%	-0.33 [-0.72 , 0.05]
Subtotal (95% CI)			**82**			**82**	**16.7%**	**-0.30 [-0.61 , 0.01]**
Heterogeneity: Tau² = 0.00; Chi² = 0.07, df = 1 (P = 0.79); I² = 0%								
Test for overall effect: Z = 1.91 (P = 0.06)								
Total (95% CI)			**492**			**492**	**100.0%**	**-0.00 [-0.24 , 0.24]**
Heterogeneity: Tau² = 0.12; Chi² = 38.30, df = 11 (P < 0.0001); I² = 71%								
Test for overall effect: Z = 0.02 (P = 0.98)								
Test for subgroup differences: Chi² = 5.64, df = 5 (P = 0.34), I² = 11.4%								

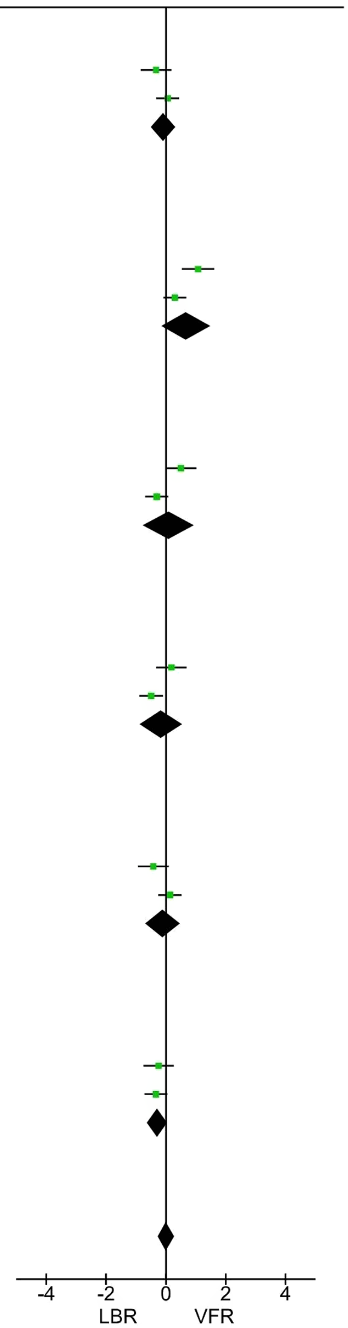

Figure 2. Meta-analysis of primary outcome parameters using the random-effects model

between 2 groups at the end of 3 months,[25] 6 months,[24,25,27] and 2 years.[26] Meta-analysis including the 2 studies[24,27] was done with a random-effects model. Low heterogeneity (I^2 = 31%) was noted. No statistically significant difference in the LII scores between the 2 retainers was noted (standard mean difference (SMD) = −0.10; *P* value = .61, 95% CI = −0.47 to 0.28) (Figure 2).

Inter-Canine and Inter-Molar Widths

Three out of 5 included studies reported that there was no statistically significant difference in ICW, and all 5 studies reported that there was no statistically significant difference in the IMW between VFRs and LBRs at any time interval, indicating adequate stability of retention in the transverse dimension with both retainers. One study showed a small but statistically significant increase of ICW in patients on VFRs.[26] Another study showed a statistically significant decrease in ICW for patients on multi-stranded stainless steel lingual retainers (MSLR).[25] Meta-analysis for ICW including the 2 studies[24,27] was done with a random-effects model. At 6th month, there was no statistically significant difference in ICW measurements between the 2 retainers (SMD = 0.66; *P* value = .09, 95% CI = −1.10 to 1.42). A high heterogeneity was observed for this parameter (I^2 = 81%) (Figure 2).

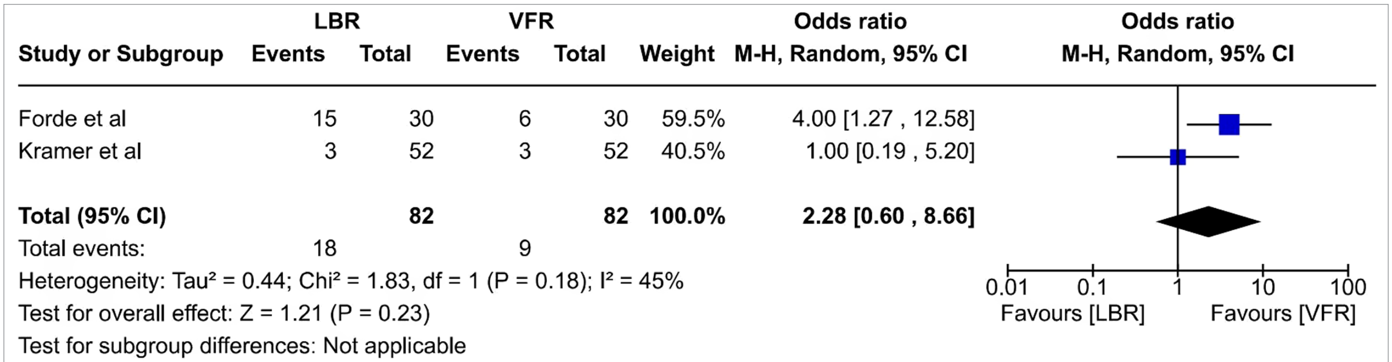

Figure 3. Meta-analysis of secondary outcome parameter (retainer failure) using odds ratio

Meta-analysis for IMW showed no statistically significant difference between the 2 retainers (SMD = 0.08; *P* value = .85, 95% CI = −0.72 to 0.87), with high heterogeneity (I^2 = 84%) which may be due to methodological differences in measuring the different parameters evaluated in the review (Figure 2).

Arch Length

Out of the 5 studies, 2 of them reported no statistically significant difference in AL between the 2 retainers.[23,26] Two studies reported an increase in AL with LBR retainers,[25,27] and 1 study reported AL reduction in both the retainers.[24] Meta-analysis involving 2 studies[24,27] revealed that there was no statistically significant difference between the 2 retainers (SMD = −0.18; *P* value = .60, 95% CI = −0.84 to 0.49) with a high heterogeneity (I^2 = 77%) (Figure 2).

Overjet and Overbite

Three out of the 5 studies had evaluated OJ and OB.[24,26,27] Two studies showed no statistically significant difference in the OJ and OB between the 2 retainers.[26,27] Only 1 study showed a small but statistically significant increase of OB in the VFR group, whereas the OJ also showed a small variation within 6-month period but was stable in the 18-month follow-up period.[24] Random-effects meta-analysis involving 2 studies[24,27] revealed that there was no significant difference in the OJ (SMD = 0.26; *P* value = .59, 95% CI = −0.71 to 1.24) and OB (SMD = −0.12; *P* value = .67, 95% CI = −0.65 to 0.42) between the 2 retainers (Figure 2).

Publication Bias

Analysis for publication bias revealed that the standard error for the ICW was high and was an outlier for 1 study. All the other primary outcome parameters also had a high standard error. Publication bias analysis for the secondary outcome parameter also revealed high standard error for retainer failure rate. Thus, publication bias was suspected (Figures 6 and 7).

Grading of Recommendations Assessment, Development, and Evaluation Assessment

The included studies revealed a very low level of certainty of evidence as assessed by the GRADE approach on the influence of retainer type for maintaining the overall stability of achieved treatment results (Table 4). On the assessment of individual outcome parameters evaluating the stability of achieved treatment results, the level of certainty of evidence for LII, AL, OJ, and OB was moderate. Inter-molar width had a low level of certainty of evidence, whereas ICW had a very low level of certainty of evidence. On the assessment of the secondary outcomes using GRADE approach, the level of certainty of evidence for periodontal status, retainer failures, and patient satisfaction was moderate.

Periodontal Status

Only 2 of the 5 included studies evaluated the periodontal status in patients receiving VFR and LBR.[22,25] Storey et al.[22] had assessed PI, GI, and CI in both groups. A statistically significant increase in the PI scores was observed in patients with LBRs at the third month evaluation when compared with the baseline evaluation. No statistically significant difference was observed in CI and GI between the 2 retainers. Alrawas et al.[25] had assessed PI, GI, BOP, and PD in CAD/CAM lingual retainer (CAD/CAM LR), MSLR, nickel-free titanium lingual retainer (SSLR), and VFR. Intergroup comparison of lower anterior teeth for periodontal health showed no statistically significant difference in PI, GI, BOP, and PD between all the 4 groups.

Retainer Failure

Two of the 5 studies had evaluated the failure rate of retainers.[24,27] One study showed a survival rate of 63.3% for LBRs and 73.3% for VFRs in maxillary arch, and 50% and 80% for LBRs and VFRs in the mandibular arch, respectively.[27] Another study showed a combined failure rate of just 5.8%, and there was no difference in retainer failure between the 2 groups.[24] Meta-analysis including the 2 studies[24,27] was done using OR. Moderate heterogeneity (I^2 = 45%) was noted. No statistically significant difference was noted in the retainer failure between the 2 retainers (OR = 2.28; *P* value = .23, 95% CI = 0.60 to 8.66) (Figure 3).

Patient Satisfaction

Two of the 5 included RCTs evaluated differences in patient satisfaction levels between the 2 retainers by using questionnaire surveys.[27] Perceived pain, discomfort, and speech difficulties were more in the patients with VFRs when compared to patients with LBRs (*P* value < .05).[27] Patients with VFRs reported soreness in mandibular arch when compared to patients with LBRs (*P* value < .05).[21] However, oral hygiene maintenance was easier in the patients with VFRs when compared to patients with LBRs.[27]

Table 3. Characteristics of selected studies

Study	Participants	Intervention/Comparison	Retention Protocol	Follow-Up Period	Outcomes and Parameters Assessed	Statistics Used	Result
O'Rouke et al.[23]	N = 82 (23 M, 59 F)	- VFR (n = 40, mean age: 16.95 ± 2.02 years) - 0.0175″ stainless steel coaxial fixed retainer (n = 42, mean age: 18.47 ± 4.41 years)	-Full time wear: first 6 months -Night time wear: next 6 months - Alternate night time wear: next 6 months	T0: Debonding T1: 6 months T2: 12 months T3: 18 months	**Treatment Stability:** LII, ICW, IMW, AL, extraction space closure.	ICC, Mann–Whitney *U* test	LBR showed more stability than VFR at 6 months, which was statistically significant. No statistical significance at the end of 12 and 18 months.
Forde et al.[27] (Part I)	N = 60 (27 M, 33 F)	- VFR (n = 30) - 0.0195″ 3-stranded twisted coaxial wire (n = 30)	-Night time wear	T0: Debonding T1: 3 months T2: 6 months T3: 12 months	**Treatment Stability:** LII, ICW, IMW, AL, OJ, OB. **Retainer survival:** Failure rate **Patient satisfaction:** Questionnaire survey	ICC, Mann–Whitney *U* test, Kaplan–Meier survival plot, log-rank test, and chi-square test	LBR showed more stability than VFR in mandibular labial segment at 12 months. LBR had more failure rate than VFR.
Storey et al.[22] (Part II)	N = 60 (27 M, 33 F)	- VFR (n = 30) - 0.0195″ 3-stranded twisted coaxial wire (n = 30)	-Night time wear	T0: Debonding T1: 3 months T2: 6 months T3: 12 months	**Periodontal health outcomes:** GI, PI, CI	Shapiro–Wilk's test, *Q–Q* plots, Mann–Whitney *U* test, repeated-measure ANOVA, Bland–Altman plots, ICC	VFR group had statistically significant reduction in plaque and calculus accumulation when compared to LBR. Gingival inflammation decreased from baseline for both groups.
Krämer et al.[24] (Part I)	N = 104 (52 M, 52 F)	- Vacuum-formed Essix C retainers (n = 52) - 0.8″ hard Remanium wire (n = 52)	-Full time wear: 7 days -Night only: 7 days to 12 months. -Every alternate night: 12-18 months -2 night per week: 18-24 months	T1: Debonding T2: 6 months T3: 18 months	**Retentive Capacity**: LII, ICW, IMW, AL, OJ, OB	Mann–Whitney *U* test, Wilcoxon signed-rank tests, Spearman's correlation coefficient test, chi-square test	VFR showed more changes in LII and OB compared to LBR. OJ, IMW, ICW were stable within both groups.
Krämer at al.[21] (Part II)	N = 104 (52 M, 52 F)	- Vacuum-formed Essix C retainers (n = 52) - 0.8″ hard Remanium wire (n = 52)	-Full time wear: 7 days -Night only: 7 days to 12 months. -Every alternate night: 12-18 months -2 night per week: 18-24 months	T1: Debonding T2: 6 months T3: 18 months	**Patient Perception:** Questionnaire Survey	Mann–Whitney *U* test, Wilcoxon signed-rank tests, crosstabs and chi-square test, Spearman's correlation test	Patients were satisfied with the treatment outcome, quality of care, and attention.

(*Continued*)

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Table 3. Characteristics of selected studies (Continued)

Study	Participants	Intervention/Comparison	Retention Protocol	Follow-Up Period	Outcomes and Parameters Assessed	Statistics Used	Result
Naraghi et al.[26]	N = 90 (54 M, 36 F)	- 0.0195″ Penta-One Steel wire - Vacuum formed Essix retainer 1.5 mm	-22/24 hours wear: First 4 weeks -Night only: 12 months -Every alternate night: 1 year post debonding	T0: Pretreatment T1: Posttreatment T2: 2 years postretention	**Treatment Stability:** LII, ICW, IMW, AL, OJ, OB	Shapiro–Wilk's test, Levene's test, Kruskal–Wallis test, Dunn's test, chi-square test, Holm–Bonferroni correction.	No statistically significant difference in LII between groups. ICW showed a statistically significant increase in VFR group. No difference in IMW, OJ, OB, and AL.
Alrawas et al.[25]	N = 60 (17 M, 43 F)	- 0.012 × 0.018-in CAD/CAM NiTi lingual wire (Robofix) (n = 15) - 0.017-in multi-stranded stainless steel lingual wire (n = 15) - 0.027 × 0.011-in single strand Nickel-free Ti lingual wire (n = 15) - VFR 1 mm (Scheu-Dental) (n = 15)	-Full time wear for 6 months	T0: posttreatment T1: 3 months T2: 6 months	**Treatment Stability:** LII, ICW, IMW, anterior dental AL. **Periodontal Status:** PI, GI, BOP, PD.	Shapiro–Wilk's test, parametric hypothesis, one-way ANOVA, Tukey's HSD post hoc test, two-way RM ANOVA, Tukey's multiple comparison test, Cronbach's alpha coefficient	No statistically significant difference in LII and IMW between groups. ICW was decreased and AL was increased for MSLR group, which was statistically significant. No statistically significant difference in PDL status.

VFR, vacuum-formed retainer; LLI, Little's Irregularity Index; ICW, inter-canine width; IMW, inter-molar width; AL, arch length; ICC, intra-class correlation coefficient; OB, overbite; OJ, overjet; GI, gingival index; PI, plaque index; CI, calculus index; RM-ANOVA, repeated measures analysis of variance; BOP, bleeding on probing; PD, probing depth; HSD, honest significant test; MSLR, multi-stranded stainless steel lingual retainer.

DISCUSSION

The present systematic review was aimed to analyze the available literature and report on the comparison of treatment stability, periodontal status, retainer failure rate, and patients' satisfaction between subjects using VFRs and LBRs after completion of orthodontic treatment. Two out of the 5 included studies reported better stability of the corrected malocclusion with LBRs than VFRs, and the remaining studies showed no difference between the 2 types of retainers. Overall periodontal health was not affected by the type of retainer used. Data on patient satisfaction revealed that speech difficulties, discomfort, and soreness of the lower arch were more in patients using VFRs. Oral hygiene maintenance was better in patients with VFRs. Failure rate of retainers was more in patients with LBRs, but the quantitative analysis revealed no statistically significant difference between the 2 groups. Risk of bias assessment revealed that 2 of the 5 included studies had a high risk of bias, whereas the other 3 studies had some concerns about the risk of bias. Quantitative analysis for treatment stability involving the 2 included studies revealed no significant difference between the 2 retainers evaluated. A very low-grade certainty of evidence suggesting no difference in treatment stability between the 2 retainers was revealed by the GRADE approach. Random-effects meta-analysis involving 2 studies was done, and SMDs were computed because different methods of measuring the outcome parameters were used in the included studies. Odds ratio was used for quantitative assessment of the secondary outcome (retainer failure).

The available systematic reviews on retainers are an aggregation of prospective cohort studies, retrospective studies, RCTs, and non-RCTs comparing removable with fixed retainers.[16-19] Littlewood et al.[29] in their systematic review had compared the amount of relapse, adverse effects on oral health, retainer survival, and patient satisfaction between Hawleys retainers, bonded retainers, and clear overlay retainers but were unable to provide a definitive conclusion due to insufficient evidence.[29] Westerlund[18] in their systematic review compared removable and fixed retainers for treatment stability, periodontal, and dental outcomes and reported that fixed retainers provided better treatment stability with low certainty of evidence. The Cochrane review by Littlewood et al.[16] reported comprehensively on different types of retainers and had also revealed differences between removable and fixed retainers. However, they too remained inconclusive due to the lack of high-quality RCTs. Al-Moghrabi et al.[17] did not evaluate treatment stability in their systematic review. Instead, they reported on periodontal outcomes, survival and failure rates, patient-reported outcomes, and cost-effectiveness, and they were unable to perform a meta-analysis due to high heterogeneity among the included studies.[17] Bahije et al.[28] in their study had evaluated the effectiveness of treatment stability between removable and fixed retention appliances and reported better stability of incisal alignment with fixed retention than removable retention, but low-quality studies limit the findings of this systematic review.

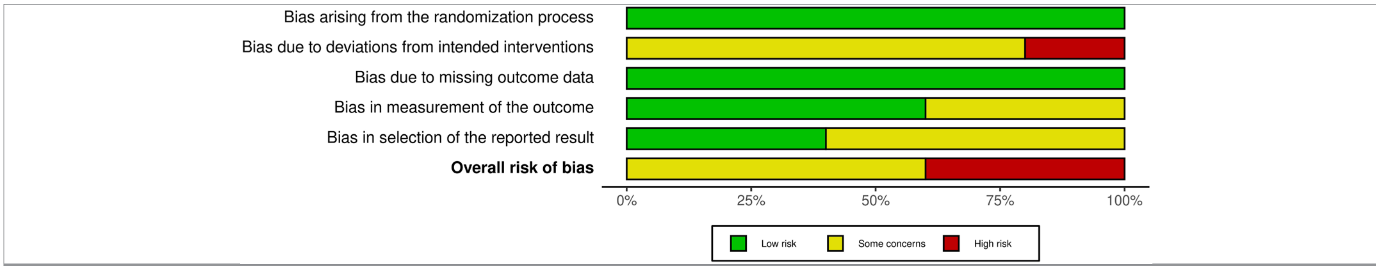

Figure 4. Risk of bias graph

The present review includes only RCTs specifically comparing VFRs and LBRs and is updated with 3 new RCTs that were not included by any previously conducted systematic reviews.[24-26] Both VFRs and LBRs are commonly used in practice even though they are indicated for specific retention requirements. A recent systematic review by Giudice et al.[30] compared removable and fixed retention appliances and came to a conclusion that fixed retention appliances provided better stability than removable retention appliances. On the contrary, the present review focused on comparing only VFRs and LBRs and the findings revealed no statistically significant difference between the 2 retainers. Inconsistencies of the findings could be attributed to the differences in the objectives and in the inclusion criteria of the 2 systematic reviews.

Treatment stability was assessed in all the included studies with the following parameters: LII, ICW, IMW, AL, OJ, and OB. Little's Irregularity Index scores increased in patients on VFRs as reported in 2 of the 5 included studies,[23,27] but when subjected to meta-analysis, there was no statistical significance (*P* value > .05). Naraghi et al.[26] reported an increase in the ICW of VFR group, which was attributed to poor adherence to VFR wear.[26] Alrawas et al.[25] reported a decrease in the ICW of the LBR group, which was attributed to width increase during treatment, leading to relapse. O'Rourke et al.[23] reported an increase in IMW of the LBR group which was due to the insufficient extent of LBRs, leading to relapse. However, when subjected to meta-analysis, no statistically significant ICW and IMW changes between the 2 retainers (*P* value > 0.001) were noted. Forde et al.[27] reported that mandibular AL had increased in patients with LBRs suggesting relapse, which was due to retainer failure. Krämer et al.[24] in their study had reported a decrease in the AL in both groups at 6 and 18 months but had not reported on intergroup comparison.[24] Alrawas et al.[25] reported an increase in the AL of the MSLR group.[25] The quantitative analysis of changes in AL, OJ, and OB revealed no statistically significant difference among patients receiving the 2 types of retainers (*P* value > .05).

The study by Krämer et al.[24] concluded that subjects using VFRs perceived more pain, discomfort, and speech difficulties in the mandibular arch than subjects using LBRs. Jäderberg et al.[31] had reported a similar finding in which the main complaint of the patients wearing VFR was soreness and speech difficulties. Incidentally, there was also an association between the wear time and pain experienced by patients in the VFR group. Oral hygiene maintenance was found to be easier in patients using VFRs. Sawhney[32] has also reported this finding in his study where patients found maintaining oral hygiene difficult with LBRs.

Periodontal status as assessed in this review was reported in studies by Storey et al.[22] and Alrawas et al.[25] Storey et al.[22] found better PI scores in patients receiving VFR than LBR, but no adverse periodontal effects were evident in both retainers.[22] Alrawas et al.[25] reported that there was no statistically significant intergroup difference for PI, GI, BOP, and PD scores. The findings of the present review for periodontal status are in consensus with the review by Arn et al.[33] in which they compared the effects of fixed retainers on the periodontal status and concluded that fixed retainers do not have any severe effect on the periodontium. Rody et al.[34] in his study had reported an increased incidence of plaque accumulation in fixed retainers than removable retainers. A retrospective study by Booth et al.[35] found a statistically significant increase in

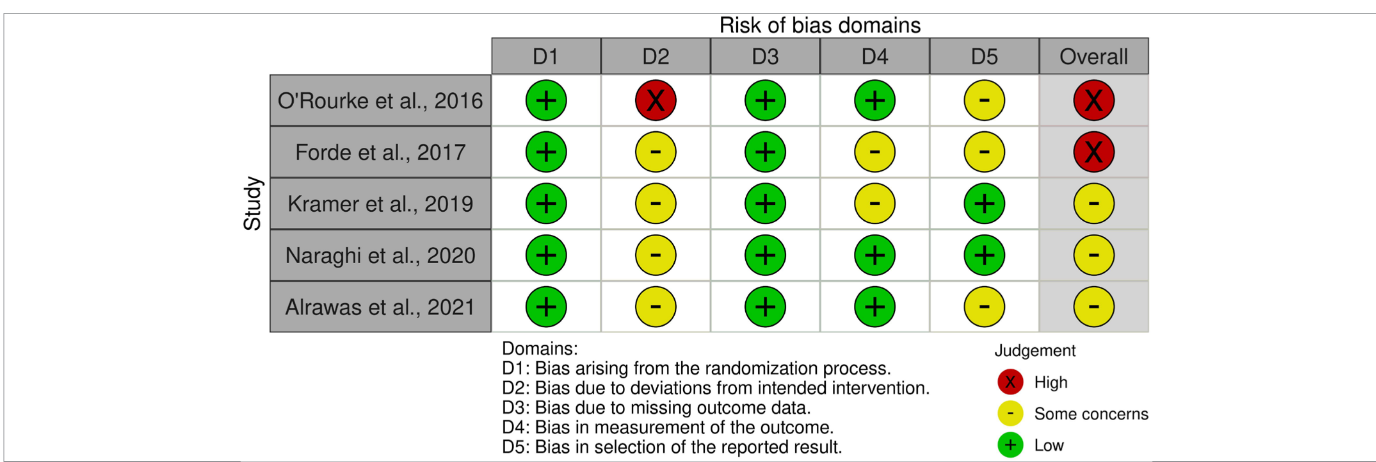

Figure 5. Risk of bias summary

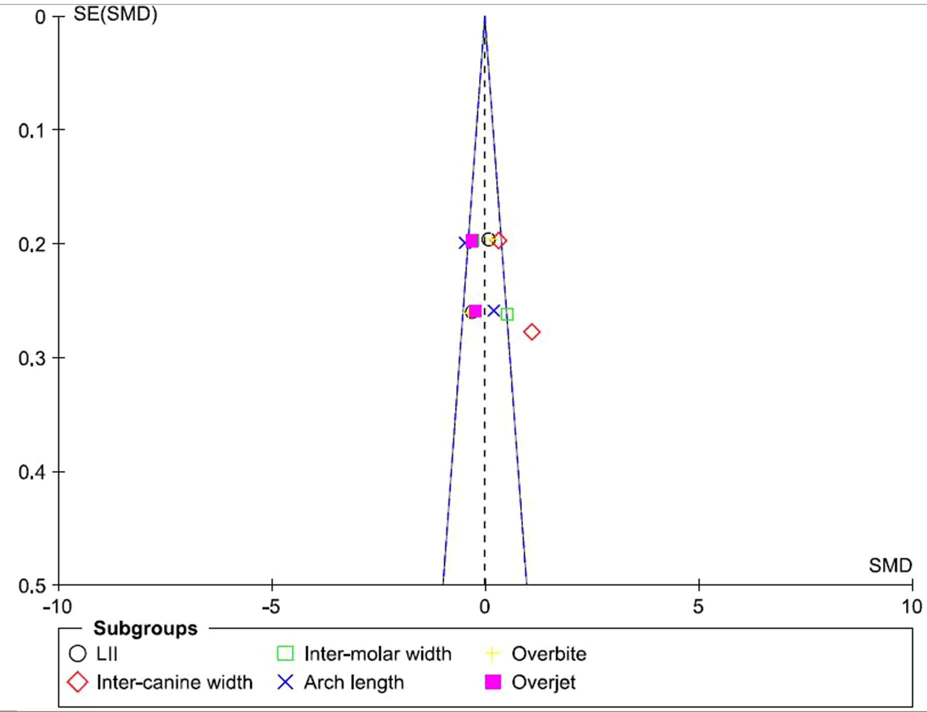

Figure 6. Funnel plot for publication bias assessment of treatment stability

PI scores near the inter-canine region of LBR as opposed to the VFR group.

Krämer et al.[24] reported that there was no difference between LBRs and VFRs in the retainer failure rate. Forde et al.[27] reported that retainer failure was more in the LBR group in the maxillary and mandibular arch than VFRs. However, the quantitative analysis revealed no difference in the retainer failure rate between VFRs and LBRs in the mandibular arch (*P* value > .05). Lingual-bonded retainers may be associated with failures because of operator experience as reported by a retrospective study conducted by Scheibe and Ruf.[36] Lingual-bonded retainer failures in the maxillary arch can be due to shearing forces as suggested by Dahl et al.[37] Krämer et al.[21] had a lower failure rate than the study by Forde et al.[27] in spite of following a night time wear-only protocol.

One of the limitations of this systematic review is the lack of sufficient number of high-quality studies. Differences in retainer dimensions and fabrication, arches involved, retainer wear protocols, outcome measurement methods, follow-up periods, and presence of inherent bias within the studies limits the scope of this review. Further high-quality trials following strict protocols

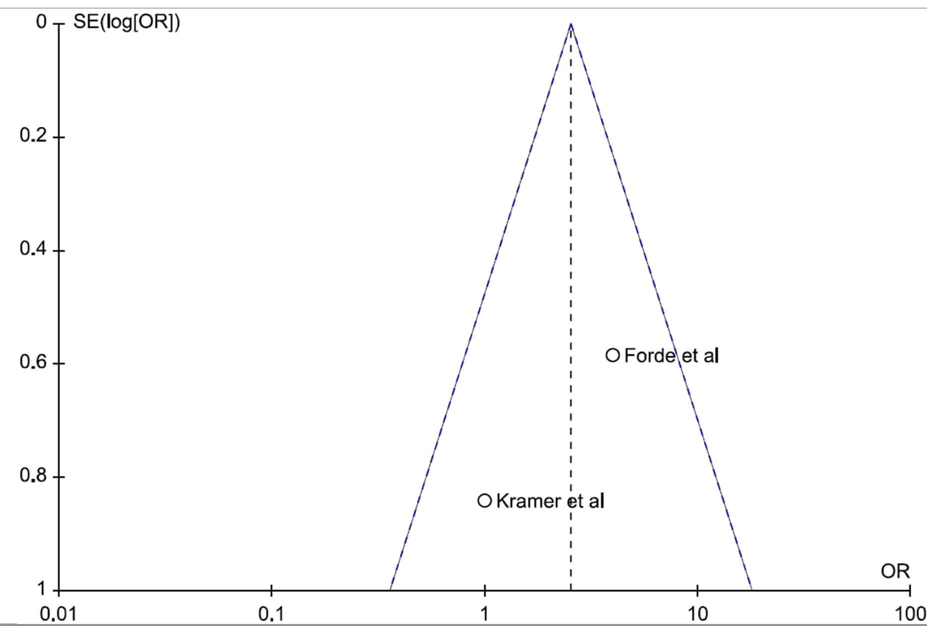

Figure 7. Funnel plot for publication bias assessment of retainer failure rate

Table 4. GRADE assessment for the level of certainty of evidence for the primary and secondary outcome parameters

Primary Outcome:

Comparison of Stability of Treatment Outcomes

Certainty Assessment							No. of Patients		Effect			
No. of Studies	**Study Design**	**Risk of Bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Other Considerations**	**BR**	**VFR**	**Relative (95% CI)**	**Absolute (95% CI)**	**Certainty**	**Importance**
Comparison of stability—Little's Irregularity Index												
2	Randomized trials	Serious[a]	Not serious	Not serious	Not serious	None	82	82	-	SMD **0.08 lower** (0.39 lower to 0.23 higher)	⨁⨁⨁◯ Moderate	CRITICAL
Comparison of stability—inter-canine width												
2	Randomized trials	Serious[a]	Serious[c]	Not serious	Not serious	Publication bias is strongly suspected	82	82	-	SMD **0.56 higher** (0.24 higher to 0.87 higher)	⨁◯◯◯ Very low	CRITICAL
Comparison of stability—inter-molar width												
2	Randomized trials	Serious[a]	Serious[c]	Not serious	Not serious	None	82	82	-	SMD **0.02 lower** (0.33 lower to 0.29 higher)	⨁⨁◯◯ Low	CRITICAL
Comparison of stability—arch length												
2	Randomized trials	Serious[a]	Not serious	Not serious	Not serious	None	82	82	-	SMD **0.24 lower** (0.55 lower to 0.07 higher)	⨁⨁⨁◯ Moderate	CRITICAL
Comparison of stability—overbite												
2	Randomized trials	Serious[a]	Not serious	Not serious	Not serious	None	82	82	-	SMD **0.07 lower** (0.37 lower to 0.24 higher)	⨁⨁⨁◯ Moderate	CRITICAL
Comparison of stability—overjet												
2	Randomized trials	Serious[a]	Not serious	Not serious	Not serious	None	82	82	-	SMD **0.3 lower** (0.61 lower to 0.01 higher)	⨁⨁⨁◯ Moderate	CRITICAL
Comparison of stability—total												
12	Randomized trials	Serious[a]	Serious[c]	Not serious	Not serious	Publication bias strongly suspected[b]	492	492	-	SMD **0.03 lower** (0.15 lower to 0.1 higher)	⨁◯◯◯ Very low	CRITICAL

SMD, standardized mean difference.
[a]Forde et al had some concerns for bias in 3 domains and Krämer et al. had some concerns for bias in 2 domains.
[b]Standard error was high and also Forde et al. was an outlier.
[c]Inconsistency in CI.

Table 4. GRADE assessment for the level of certainty of evidence for the primary and secondary outcome parameters (Continued)

Secondary Outcome:
Periodontal Status (Assessed with Plaque Index, Gingival Index, Calculus Index, Bleeding on Probing, Periodontal Pocket Depth)

Certainty Assessment							Impact	Certainty	Importance
No. of Studies	**Study Design**	**Risk of Bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Other Considerations**			
2	Randomized trials	Serious[a]	Serious[b]	Not serious	Not serious[c]	All plausible residual confounding would reduce the demonstrated effect	There is an increase in the plaque index score in LBR compared to VFR at third month of assessment. No difference in gingival and calculus indices, bleeding on probing, and periodontal pocket depth	⨁⨁⨁◯ Moderate	NOT IMPORTANT

VFR, vacuum-formed retainer; LBR, lingual-bonded retainer.
[a]Storey et al. had some concerns for bias in 3 domains and Alrawas et al. has some concerns for bias in 2 domains.
[b]Inconsistency in reporting the measurements.

Table 4. GRADE assessment for the level of certainty of evidence for the primary and secondary outcome parameters (Continued)

Retainer Failure

Certainty Assessment							No. of Patients		Effect		Certainty	Importance
No. of Studies	**Study Design**	**Risk of Bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Other Considerations**	**LBR**	**VFR**	**Relative (95% CI)**	**Absolute (95% CI)**		
2	Randomized trials	Serious[a]	Not serious	Not serious	Not serious	Publication bias strongly suspected all plausible residual confounding would reduce the demonstrated effect[b]	18/82 (22.0%)	9/82 (11.0%)	**OR** 2.28 (0.60 to 8.66)	**110 more per 1000** (from 41 fewer to 407 more)	⨁⨁⨁◯ Moderate	IMPORTANT

OR, odds ratio; VFR, vacuum-formed retainer; LBR, lingual-bonded retainer.
[a]Forde et al. had some concerns for bias in 3 domains and Krämer et al. had some concerns for bias in 2 domains.
[b]High standard error (log(OR)).

Table 4. GRADE assessment for the level of certainty of evidence for the primary and secondary outcome parameters (Continued)

Patient Satisfaction (Follow-Up: 12 Months; Assessed with Validated Questionnaire)

Certainty Assessment							Impact	Certainty	Importance
No. of Studies	**Study Design**	**Risk of Bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Other Considerations**			
2	Randomized trials	Serious[a]	Serious[b]	Not serious	Not serious	All plausible residual confounding would suggest spurious effect, while no effect was observed	Pain, discomfort, and speech difficulties were more for VFR compared to LBR. However, oral hygiene maintenance was easier in VFR.	⨁⨁⨁◯ Moderate	NOT IMPORTANT

VFR, vacuum-formed retainer; LBR, lingual-bonded retainer.
[a]Forde et al had some concerns for bias in 3 domains, Krämer et al. has some concerns for bias in 2 domains.
[b]Inconsistency in measurement scale and domains to assess patient satisfaction.

and standard methodologies are required to evaluate the periodontal status and retainer survival rate of VFRs and LBRs as it could help establish its efficiency for long-term usage.

CONCLUSION

Within the limitations of this systematic review, very low certainty of evidence suggests that there is no difference in treatment stability following the use of either VFRs or LBRs after completion of orthodontic treatment. A moderate level of certainty of evidence suggests that there is no difference in periodontal status and retainer failure rate in patients receiving either of the 2 retainers. Also, VFRs are associated with more discomfort and soreness when compared with LBRs and oral hygiene maintenance was better in subjects receiving VFRs.

Both VFRs and LBRs are equally effective in maintaining treatment results and the choice of retainer depends on either operator preference or the patient's choice. Research implications include conducting well-planned, standardized, and long-term studies in the near future that will aid the clinician in making a more evidence-based decision on the choice of retainer.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - S.H., S.S.; Design - S.H., S.S.; Supervision - S.H., S.S.; Data Collection and/or Processing - A.B.; Analysis and/or Interpretation - A.B.; Literature Review - A.B.; Writing - S.H., S.S.; Critical Review - A.B.

Acknowledgments: I would like to acknowledge the efforts of my co-guides along with our Head of the Department, Dr. Aravind Kumar, and our Director, Dr. Deepak Nallaswamy for encouraging us to get involved in interdisciplinary research topics involving matters of concern for orthodontic purposes.

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

Funding: The authors declared that this study has received no financial support.

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Appendix 1. Studies Excluded with Reasons (n = 5)

Reasons for Exclusion	Number of Studies
Studies not assessing treatment stability	3[14,38,39]
VFR and LBR in the same group	1[40]
Follow-up RCT	1[41]

RCT, randomized controlled trial; VFR, vacuum-formed retainer; LBR, lingual-bonded retainer.