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ORIGINAL ARTICLE

Effect of piezocision on molar intrusion in open-bite treatment using a modified MEAW technique

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Abstract

Purpose The aim of this retrospective study was to investigate whether a piezocision technique influences molar intrusion in open-bite cases.

Methods In all, 30 patients with open-bite malocclusion were assigned to one of two groups: the piezocision group comprised 15 patients who were treated using curved arches and anterior elastics with the simultaneous combination of piezocision which was performed interdentally in the upper posterior region, while the control group comprised 15 patients who were treated with the same treatment mechanics without piezocision. In both groups, after leveling and aligning, upper 0.017 × 0.025 accentuated curve and lower 0.017 × 0.025 reversed curve of Spee NiTi archwires were placed. Anterior vertical elastics were applied between laterals and the canines on both sides. The effects of treatments were investigated on cone-beam computed tomography images acquired before use of elastics and after correction of open-bite.

Results Open-bite closure was achieved in 2.85 ± 0.85 and 4.1 ± 1.58 months in the piezocision and control groups, respectively, while total treatment lasted 1.4 ± 0.42 and 1.7 ± 0.43 years, respectively. Extrusion of lower posterior teeth ($p < 0.05$) was observed together with extrusion of incisors and canines ($p < 0.001$) in the piezocision group, while only incisors and canines were extruded in the control group ($p < 0.001$). There were no significant differences between the groups ($p > 0.05$) except significant lower incisor extrusion ($p < 0.05$) and counter-clockwise rotation of the lower occlusal plane in the piezocision group ($p < 0.001$).

Conclusion The duration of open-bite correction was significantly shorter in the piezocision group. No molar intrusion was observed in either group. Open bite correction was achieved mainly by extrusion and retrusion of the incisors while maintaining upper molar positions.

Keywords Multiloop edgewise archwire · Regional accelerated phenomenon · Tooth movement techniques · Orthodontic appliances, fixed · Piezosurgery

All data generated or analyzed during this study are included in the published article.
There is no unreported software application or custom code in this study.

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Wirkung der Piezozision auf die Molarenintrusion bei der Behandlung eines offenen Bisses mittels einer modifizierten MEAW-Technik

Zusammenfassung

Ziel Ziel dieser retrospektiven Studie war es, zu prüfen, ob eine Piezozisionstechnik die Molarenintrusion bei einem offenen Biss beeinflusst.

Methoden Insgesamt 30 Patienten mit einer offenen Bissfehlstellung wurden einer von 2 Gruppen zugeordnet: Die Piezozisionsgruppe umfasste 15 Patienten, die behandelt wurden mit gekrümmten Bögen und anterioren Elastics in Kombination mit gleichzeitiger Piezozision, die interdental im oberen Seitenzahnbereich durchgeführt wurde. Die Kontrollgruppe umfasste 15 Patienten, die mit der gleichen Behandlungsmechanik, aber ohne die Verwendung von Piezozision behandelt wurden. In beiden Gruppen wurden nach Nivellierung und Ausrichtung im Oberkiefer 0,017 × 0,025 akzentuierte NiTi-Spee-Bögen und im Unterkiefer 0,017 × 0,025 umgekehrte Spee-NiTi-Bögen platziert. Anteriore vertikale Elastics wurden zwischen den seitlichen Schneidezähnen und den Eckzähnen auf beiden Seiten angebracht. Die Auswirkungen der Behandlungen wurden auf DVT(digitale Volumentomographie)-Bildern untersucht, die vor dem Einsatz von Elastics und nach der Korrektur des offenen Bisses aufgenommen wurden.

Ergebnisse Ein Verschluss des offenen Bisses wurde in 2,85 ± 0,85 Monaten in der Piezozisions- und nach bzw. 4,1 ± 1,58 Monaten in der Kontrollgruppe erreicht, wobei die Gesamtbehandlung 1,4 ± 0,42 bzw. 1,7 ± 0,43 Jahre dauerte. Die Extrusion der unteren Seitenzähne ($p < 0{,}05$) wurde zusammen mit der Extrusion der Schneide- und Eckzähne ($p < 0{,}001$) in der Piezozisionsgruppe beobachtet, während in der Kontrollgruppe nur die Schneide- und Eckzähne extrudiert wurden ($p < 0{,}001$). Es gab keine signifikanten Unterschiede zwischen den Gruppen ($p > 0{,}05$), mit Ausnahme der signifikanten Extrusion der unteren Schneidezähne ($p < 0{,}05$) und der Drehung der unteren Okklusionsebene gegen den Uhrzeigersinn in der Piezozisionsgruppe ($p < 0{,}001$).

Schlussfolgerung Die Dauer der Korrektur des offenen Bisses war in der Piezozisionsgruppe signifikant kürzer. In beiden Gruppen wurde keine molare Intrusion beobachtet. Die Korrektur des offenen Bisses wurde hauptsächlich durch Extrusion und Retrusion der Schneidezähne unter Beibehaltung der oberen Molarenpositionen erreicht.

Schlüsselwörter Multiloop edgewise archwire · Regional beschleunigtes Phänomen · Verfahren zur Zahnbewegung · Festsitzende kieferorthopädische Apparaturen · Piezochirurgie

Introduction

Anterior open-bite, depending on the severity and the causative factors, can be one of the most difficult malocclusions to treat and to ensure stability [1]. One of the causes of the development of open-bite is overeruption of the upper molars due to multiple etiological factors. Therefore, intrusion of the posterior teeth or at least prevention of molar extrusion during orthodontic treatment is crucial for vertical control in open-bite patients since 1–4 mm of molar extrusion was reported during any fixed orthodontic treatment [2, 3].

In 1987, Kim [4] developed the multiloop edgewise archwire (MEAW) technique which is comprised of anterior vertical elastics and stainless steel (SS) archwires with an accentuated curve of Spee in the maxilla and a reverse curve of Spee in the mandible combined with distally angulated boot loops to control the posterior segments. With this technique, open-bite is said to be closed by the extrusion of anterior teeth and uprighting of the posterior teeth causing clockwise rotation of the maxillary occlusal plane and counterclockwise rotation of the mandibular occlusal plane. However, this technique requires high professional skills [5]. To simplify the MEAW technique, Enacar et al. [6] modified Kim's technique by using upper accentuated and lower reverse curved nickel–titanium (NiTi) archwires with vertical elastics which were applied in the canine regions and they reported similar treatment results to those obtained with the MEAW technique. Kucukkeles et al. [7] and Atout et al. [8] reported the technique as being less time consuming since there is no need for wire bending, more hygienic and less irritating for the soft tissues. However, all these studies were performed analyzing two-dimensional (2D) measurements which are not reliable considering superposition of the right and left landmarks. Therefore, when the intrusion effect on posterior teeth is investigated, cone-beam computed tomography (CBCT) images provide more accurate evaluations. Recently, Erdem and Kucukkeles [9] investigated the effects of this modified technique with CBCT and reported vertical control of molars during the open-bite closure.

In the literature, there are also case reports explaining that with the application of a corticotomy more efficient molar intrusion was achieved [10, 11]. Mostafa et al. [12] performed corticotomy between the roots of the upper anterior teeth in open-bite patients and claimed that the amount

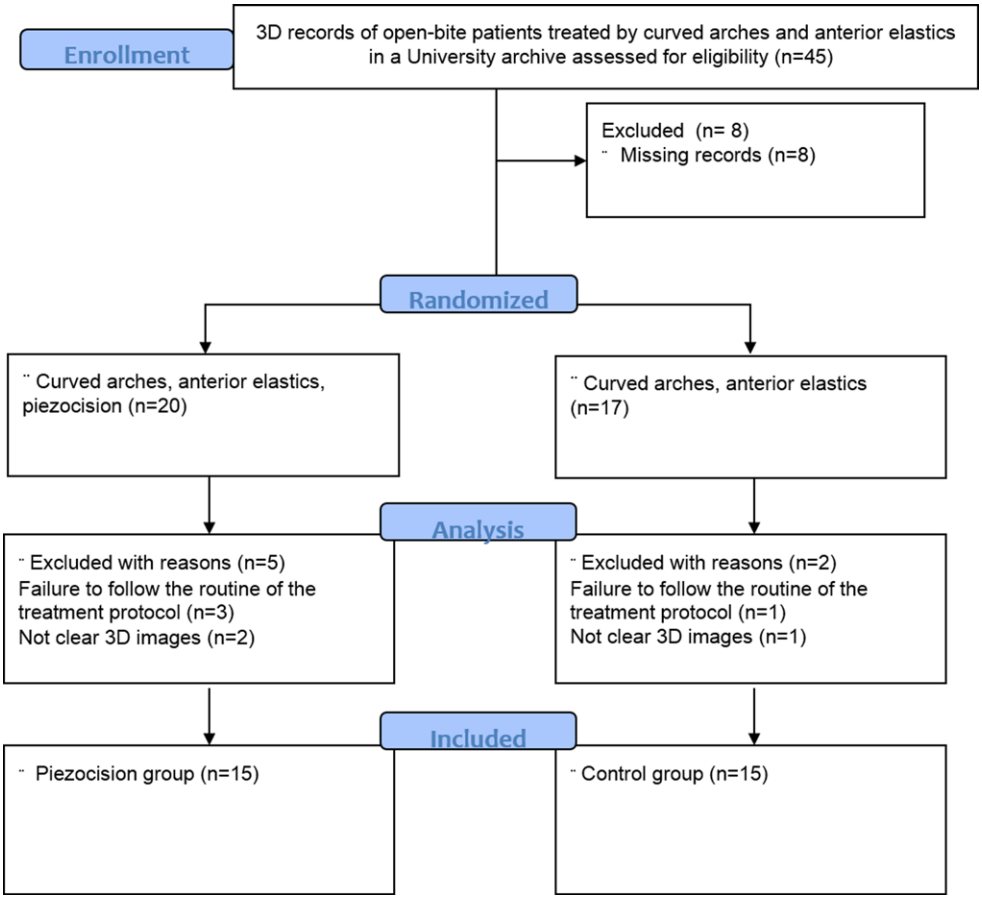

Fig. 1 Flow diagram of patient selection based on the CONSORT (Consolidated Standards of Reporting Trials) statement guidelines
Abb. 1 Flussdiagramm zur Patientenauswahl auf Basis der CONSORT(Consolidated Standards of Reporting Trials)-Statement-Leitlinien

of upper incisor extrusion exceeded the lower incisor extrusion because the corticotomies initiated the regional accelerated phenomenon (RAP) around the upper teeth [13]. Since corticotomy surgeries require full-thickness flaps and cause morbidity and postsurgical discomfort, minimally invasive and flapless alternatives have been developed such as piezopuncture [14], microosteoperforations [15], or piezocision [16, 17]. The piezocision procedure consists of flapless corticotomies through vertical interproximal incisions using a piezoelectric device. The piezoelectric knife is used to decorticate the alveolar bone through the microincisions on the buccal gingiva in order to initiate RAP which is characterized by a decrease in bone density and an increase in bone turnover [18], leading to faster orthodontic tooth movement. Also, the period of RAP is reported to begin within a few days after surgery, usually peaks in 1–2 months, and then slows down and disappears as remineralization sets in [19]. Therefore, researchers have focused on using piezocision for accelerating orthodontic tooth alignment and some studies have found this technique effective [20–22], while others have concluded the opposite [23].

Studies [20, 21] evaluating canine retraction with the help of piezocision reported faster distalization when compared to the control group. Other studies in which piezocision was performed in crowding cases revealed acceleration in tooth movement during alignment [16, 24, 25] and greater efficiency in the maxilla [24]. It was also reported that piezocision was effective in accelerating orthodontic treatment during 3 months after surgery [24].

Thus, an important question arises. Do less invasive interventions such as piezocision achieve efficient molar intrusion? As piezocision is also reported to initiate a RAP effect and shortening effect of treatment time, the aim of this study was to investigate whether it is possible to accelerate the tooth movement and achieve molar intrusion when piezocision is performed in the posterior region with the combination of curved NiTi arches and anterior vertical elastics so that the clinicians can decide whether this technique is worth applying in open-bite cases.

Materials and methods

Protocol registration

This single-center, single-blinded retrospective study was reviewed and approved by the ethical committee of Mar-

mara University, Institute of Health Sciences, Istanbul, Turkey (2019-354). The CBCT records of 45 patients with anterior open-bite treatment using the described technique were retrieved from the archives of the Department of Orthodontics, Faculty of Dentistry, Marmara University, Istanbul, Turkey. Written informed consents were signed by all patients/parents willing to participate in this study.

Eligibility criteria

The inclusion criteria were as follows:

- Patients with full eruption of all teeth,
- Class I or mild class II skeletal and dental relationship,
- Mild to moderate open-bite, and
- Normal or minimally increased facial height.

The exclusion criteria were as follows:

- Patients with missing teeth,
- Craniofacial anomalies,
- Missing and unclear records,
- Patients who were reported failure to follow the routine of the treatment protocol,
- Patients having systemic, hormonal, or congenital disease, or
- Patients with altered bone metabolism (e.g., due to antiresorptive drug, steroids or immunosuppressant use).

The flow diagram of patient selection based on the CONSORT (Consolidated Standards of Reporting Trials) statement is shown in Fig. 1. Finally, 30 patients were assigned to one of two groups according to whether piezocision was performed or not. All the patients were treated using curved arches and anterior vertical elastics; however, piezocision was performed in 15 patients (piezocision group) and no piezocision was performed on the other 15 patients (control group). The treatment of the piezocision group was done by one orthodontist and the piezocisions were performed by the same orthodontist. The treatment of the control group was carried out by another orthodontist.

Sample size collection

Sample size estimation was based on a previous study by Kucukkeles et al. [7] and a minimum of 15 patients for each group was required (power of 0.80; α level of 0.05).

Orthodontic procedure

All the patients were treated with 0.022 inch slot MBT metal brackets. Both maxillary and mandibular teeth, including second molars, were leveled and aligned with superelastic NiTi archwires. Following this stage, 0.017 × 0.025 inch maxillary accentuated curve of Spee and mandibular reverse curve of Spee NiTi archwires were placed and CBCT images were taken (T0). Surgical hooks were crimped between central and lateral incisors in both arches and vertical box elastics were applied between crimped hooks and the canine bracket hooks on both sides for all day except during meals.

In both groups, after the achievement of 2 mm positive overbite, the patients were instructed to use their elastics for another 6–8 weeks on 0.017 × 0.025 inch straight SS archwires. Then the second CBCT images were taken (T1).

Piezocision procedure

In the piezocision group, just before the anterior vertical elastics use, vertical interproximal incisions with a length of 4 mm were performed 4 mm above the interdental papillae on the soft tissue under local anesthesia. These incisions were done interproximally between the upper canine and second molars on both sides. Then 3 mm depth and 4 mm length of alveolar cortical incisions were performed with a piezosurgery knife (no. 0T7) by using a Mectron Piezosurgery® 3 device (Mectron, Genova, Italy) (Fig. 2). No sutures were applied following the procedure. Treatment records of one patient from the piezocision group are shown in Figs. 3 and 4.

Data collection

The effects of the treatment were investigated on CBCT images and cephalograms derived from the CBCTs which were acquired before the usage of elastics (T0) and after the correction of open-bite (T1). The CBCT images were acquired using an Iluma® Imtec Imaging Machine (3M, Ardmore, OK, USA). The DICOM data were transferred to

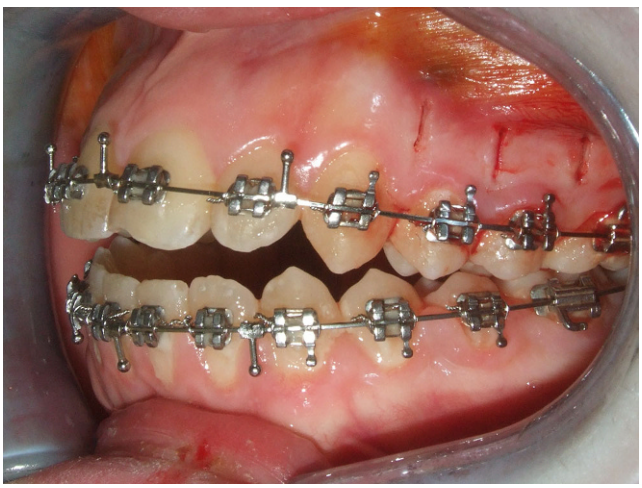

Fig. 2 Intraoral photo showing the piezocision region
Abb. 2 Intraorale Aufnahme der Piezozisionregion

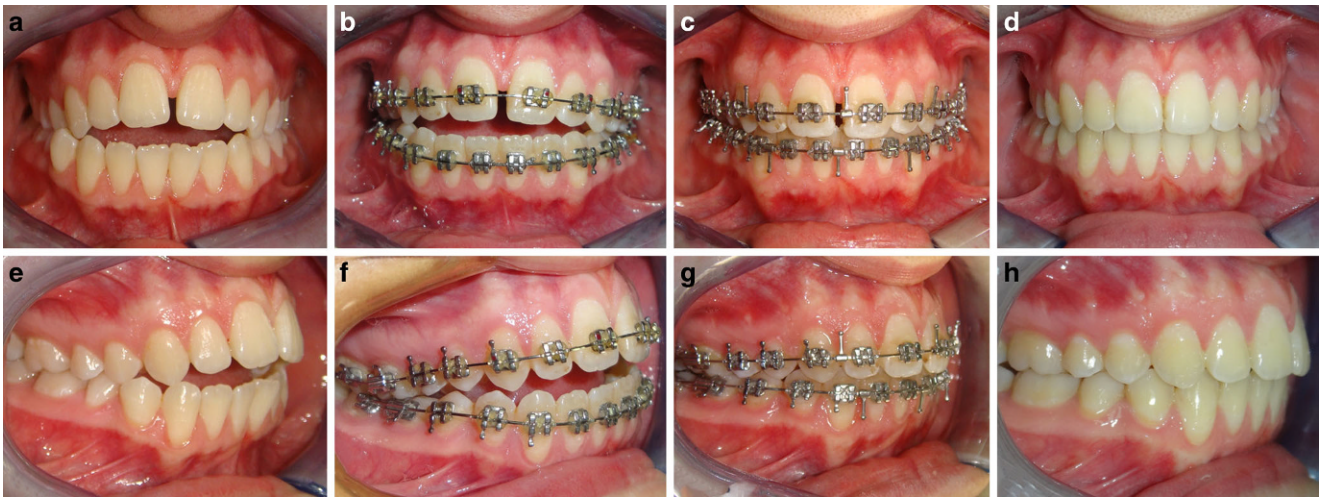

Fig. 3 Intraoral photographs of a patient at each stage of treatment; (**a**, **e**) initial; (**b**, **f**) before use of vertical elastics; (**c**, **g**) after correction of the open bite; (**d**, **h**) final
Abb. 3 Intraorale Aufnahmen eines Patienten in jeder Behandlungsphase: (**a**, **e**) zu Beginn; (**b**, **f**) vor der Verwendung von vertikalen Gummibändern; (**c**, **g**) nach Korrektur des offenen Bisses; (**d**, **h**) zum Abschluss der Behandlung

Fig. 4 Extraoral photographs of a patient at each stage of treatment; (**a**, **e**) initial; (**b**, **f**) before use of vertical elastics; (**c**, **g**) after correction of the open bite; (**d**, **h**) final
Abb. 4 Extraorale Aufnahmen eines Patienten in jeder Behandlungsphase: (**a**, **e**) zu Beginn; (**b**, **f**) vor der Verwendung von vertikalen Gummibändern; (**c**, **g**) nach Korrektur des offenen Bisses; (**d**, **h**) zum Abschluss der Behandlung

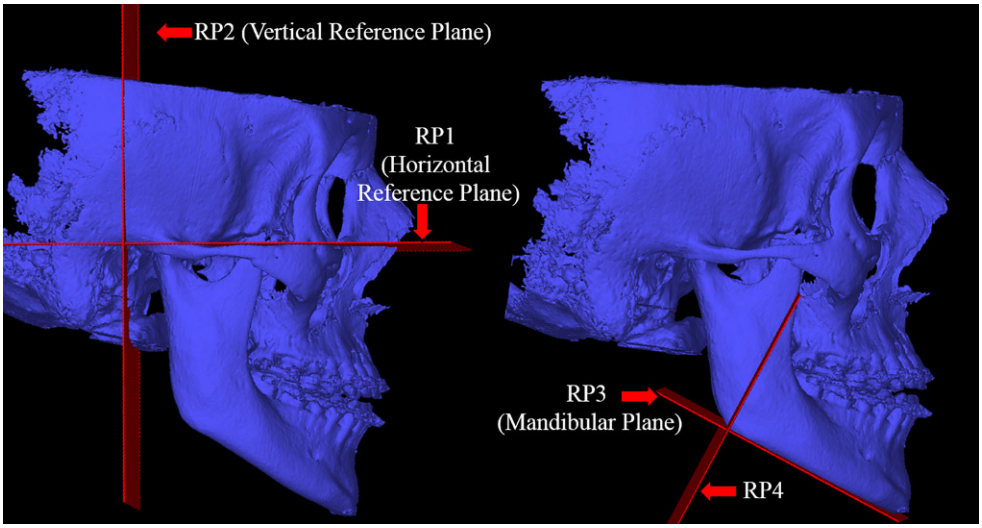

Fig. 5 Reference planes (RP1, RP2, RP3, and RP4)
Abb. 5 Referenzebenen (RP1, RP2, RP3 und RP4)

Table 1 Dental reference points used on the three-dimensional images
Tab. 1 Auf den dreidimensionalen Bildern verwendete zahnmedizinische Referenzpunkte

Point	Definition
U1R	Midmost point of the upper right first incisor's incisal edge
U3R	Midmost point of upper right canine tip
U3L	Midmost point of upper left canine tip
U5R	Buccal cusp tip of upper right second premolar
U5L	Buccal cusp tip of upper left second premolar
U6L	Trifurcation of upper left first molar
U6R	Trifurcation of upper right first molar
U7L	Trifurcation of upper left second molar
U7R	Trifurcation of upper right second molar
L1R	Midmost point of the lower right central incisor's incisal edge
L3R	Midmost point of the lower right canine tip
L3L	Midmost point of the lower left canine tip
L5R	Buccal cusp tip of the lower right second premolar
L5L	Buccal cusp tip of the lower left second premolar
L6L	Trifurcation of lower left first molar
L6R	Trifurcation of lower right first molar
L7L	Trifurcation of lower left second molar
L7R	Trifurcation of lower right second molar

MIMICS 19.0 software (Materialise Europe, Leuven, Belgium) and three-dimensional (3D) images were created.

Following reference planes were created on 3D images (Fig. 5) and linear measurements from the dental points (Table 1) to the reference planes were made accordingly.

- RP1 (Frankfort horizontal plane): The plane passing from the right and left porions and the right infraorbital point.
- RP2: The vertical reference plane that passes through the right and left porions and perpendicular to RP1.

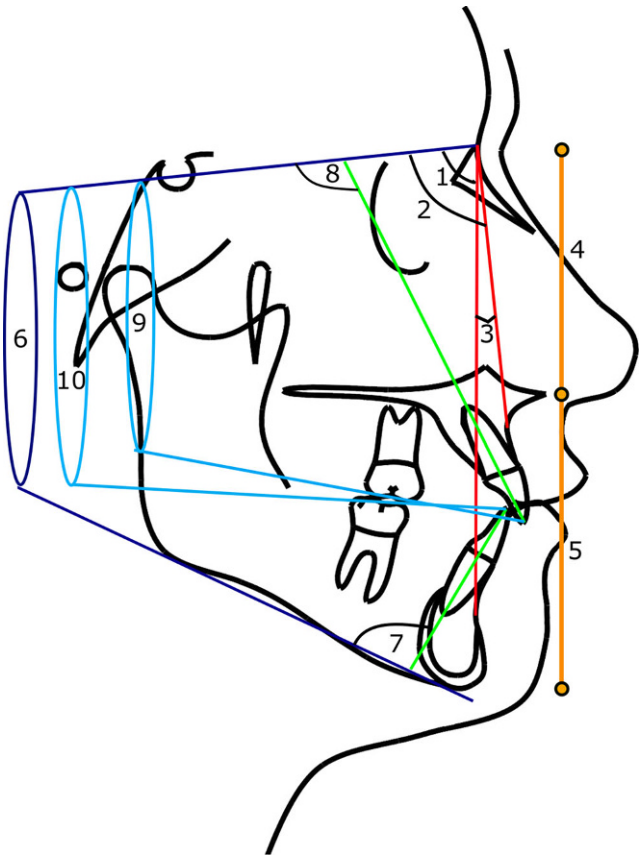

Fig. 6 Measurements used for cephalometric evaluation: *1* SNA (°), *2* SNB (°), *3* ANB (°), *4* N-ANS (mm), *5* ANS-Me (mm), *6* SN-MP (°), *7* IMPA (°), *8* U1-SN (°), *9* SN-UOP (°), *10* SN-LOP (°)
Abb. 6 Zur kephalometrischen Auswertung verwendete Messwerte: *1* SNA (°), *2* SNB (°), *3* ANB (°), *4* N-ANS (mm), *5* ANS-Me (mm), *6* SN-MP (°), *7* IMPA (°), *8* U1-SN (°), *9* SN-UOP (°), *10* SN-LOP (°)

- RP3 (mandibular plane): The plane passing from the right and left gonions to menton.
- RP4: The vertical reference plane that passes through the right and left gonions and perpendicular to RP3.

In addition, 7 angular and 4 linear parameters were measured on the constructed cephalometric images (Fig. 6).

All measurements were performed by the same examiner who was blinded to the type of treatment protocol and was not involved in treating the patients.

Statistical analysis

IBM SPSS® Statistics for Windows, version 22.0 (IBM Corp., Armork, NY, USA) was used for statistical analysis. To assess intraexaminer reliability, the measurements were repeated for six randomly selected patients 1 week after the first measurements. Distribution of the data was analyzed with the Kolmogorov–Smirnov test. The Student t-test was used for intergroup comparisons of the parameters with normal distribution. The paired-samples t-test was used for within-group comparisons of parameter changes from T1 to T0. The intraclass correlation coefficient (ICC) was calculated for analyzing the method error. Significance was evaluated at a level of $P < 0.05$.

Results

All measurements were repeated by the same operator. ICCs, which were calculated for each variable to assess the reliability of the measurements, ranged from 0.871 to 1.000 and showed a high level of agreement.

Patient characteristics

The mean age of the patients in the piezocision group was 18.65 ± 2.51 years, while that of patients in the control group was 18.26 ± 2.96 years. Total treatment time was 1.4 ± 0.42 and 1.7 ± 0.43 years, respectively. There was no statistically significant difference between the groups in terms of the mean age, total treatment time, and the leveling–aligning duration ($p < 0.05$). However, a statistically significant difference was found between the two groups in terms of T1–T0 duration (Table 2).

Cephalometric variables at T0 were similar between the groups, except for overjet (higher in the piezocision group) and anterior facial height (higher in the control group; Table 3).

Table 2 Initial treatment ages and duration of vertical elastics usage
Tab. 2 Alter bei Erstbehandlung und Dauer der Verwendung vertikaler Elastics

	Piezocision group ($n = 15$)	Control group ($n = 15$)	p
	Mean ± SD	Mean ± SD	
Initial treatment age (years)	18.65 ± 2.51	18.26 ± 2.96	0.384
Leveling and aligning (months)	14 ± 5.4	16.4 ± 5.42	0.234
T1–T0 (months)	2.85 ± 0.85	4.1 ± 1.58	0.012*
Total treatment (years)	1.4 ± 0.42	1.7 ± 0.43	0.062

Samples t test
SD standard deviation, *T0* before use of vertical elastics, *T1* after correction of the open bite
*$p < 0.05$

Table 3 Evaluation of initial values of skeletal and dental parameters
Tab. 3 Evaluierung skelettaler und dentaler Parameter vor Behandlungsbeginn

T0	Piezocision Mean ± SD (p)	Control Mean ± SD (p)	p
SNA (°)	80.33 ± 3.88	79.73 ± 4	0.680
SNB (°)	76.53 ± 4.17	75.87 ± 2.87	0.614
ANB (°)	3.93 ± 2.84	3.63 ± 2.14	0.746
N-ANS (mm)	54.13 ± 3.33	58.26 ± 1.4	0.001**
ANS-Me (mm)	77.31 ± 6.77	68.12 ± 16.27	0.053
SN-MP (°)	40.6 ± 6.43	39.2 ± 4.26	0.488
IMPA (°)	96.4 ± 5.93	95.4 ± 4.86	0.618
U1-SN (°)	107 ± 4.67	105.93 ± 4.65	0.536
SN-UOP (°)	15.27 ± 3.69	14.93 ± 3.45	0.800
SN-LOP (°)	18.93 ± 4.44	17.86 ± 2.89	0.443
OVERJET (mm)	4.61 ± 1.9	2.71 ± 1.16	0.003**
OVERBITE (mm)	–2.06 ± 1.62	–2.03 ± 1.64	0.956

Student t test
SD standard deviation, *T0* before use of vertical elastics
*$p < 0.05$, **$p < 0.01$

Cephalometric findings

There were no significant differences between the groups with regard to changes in skeletal parameters except the SN-MP angle (Table 4; Fig. 7). Measurements for IMPA (6.4 ± 3.11° in the piezocision group; 6.47 ± 3.44° in the control group) and U1-SN (8.13 ± 3.66° in piezocision group; 5.53 ± 4.65° in the control group) decreased significantly in both groups. SN-UOP increased in both groups, whereas SN-LOP decreased only in the piezocision group and the difference between the groups regarding SN-LOP was significant. All patients finished the treatment with a positive overbite and the achieved changes were significant in both groups.

Table 4 Intra- and intergroup comparisons of skeletal and dental parameters measured on cephalometric images at T0 and T1
Tab. 4 Intra- und Inter-Gruppen-Vergleiche skelettaler und dentaler Parameter, gemessen auf kephalometrischen Bildern bei T0 und T1

	Piezocision			Control			Piezocision vs control p^b
	T0	T1	Difference mean ± SD (p)[a]	T0	T1	Difference mean ± SD (p)[a]	
SNA (°)	80.33 ± 3.88	80.33 ± 3.85	0 ± 0.75	79.73 ± 4	80.13 ± 3.66	0.4 ± 1.24	0.296
SNB (°)	76.53 ± 4.17	76.27 ± 4.31	–0.27 ± 0.7	75.87 ± 2.87	76 ± 2.69	0.13 ± 1.12	0.253
ANB (°)	3.93 ± 2.84	4.07 ± 2.63	0.13 ± 0.74	3.63 ± 2.14	4.06 ± 2.31	0.43 ± 1.32	0.450
N-ANS (mm)	54.13 ± 3.33	54.67 ± 3.04	0.54 ± 1.41	58.26 ± 1.4	58.21 ± 1.4	–0.05 ± 0.75	0.167
ANS-Me (mm)	77.31 ± 6.77	77.82 ± 5.91	0.51 ± 2.48	68.12 ± 16.27	68.58 ± 16	0.46 ± 2.27	0.952
SN-MP (°)	40.6 ± 6.43	40.87 ± 6.38	0.27 ± 1.03	39.2 ± 4.26	40.6 ± 4.1	1.4 ± 1.59**	0.028*
IMPA (°)	96.4 ± 5.93	90 ± 6.6	–6.4 ± 3.11***	95.4 ± 4.86	88.93 ± 5.82	–6.47 ± 3.44***	0.956
U1-SN (°)	107 ± 4.67	98.9 ± 5.01	–8.13 ± 3.66***	105.93 ± 4.65	100.4 ± 4.71	–5.53 ± 4.65***	0.100
SN-UOP (°)	15.27 ± 3.69	20.13 ± 5.84	4.87 ± 3.09***	14.93 ± 3.45	18.66 ± 3.69	3.73 ± 3.39***	0.347
SN-LOP (°)	18.93 ± 4.44	15.87 ± 5.31	–3.07 ± 2.31***	17.86 ± 2.89	18.06 ± 2.93	0.2 ± 1.37	0.001***
OVERJET (mm)	4.61 ± 1.9	4.04 ± 1.32	–0.57 ± 1.92	2.71 ± 1.16	3.1 ± 0.62	0.4 ± 1.24	0.114
OVERBITE (mm)	–2.06 ± 1.62	2.69 ± 0.9	4.75 ± 2.04***	–2.03 ± 1.64	2.4 ± 0.6	4.43 ± 1.65***	0.634

SD standard deviation, *T0* before use of vertical elastics, *T1* after correction of the open bite
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$
[a]Paired-samples t test
[b]Student t test

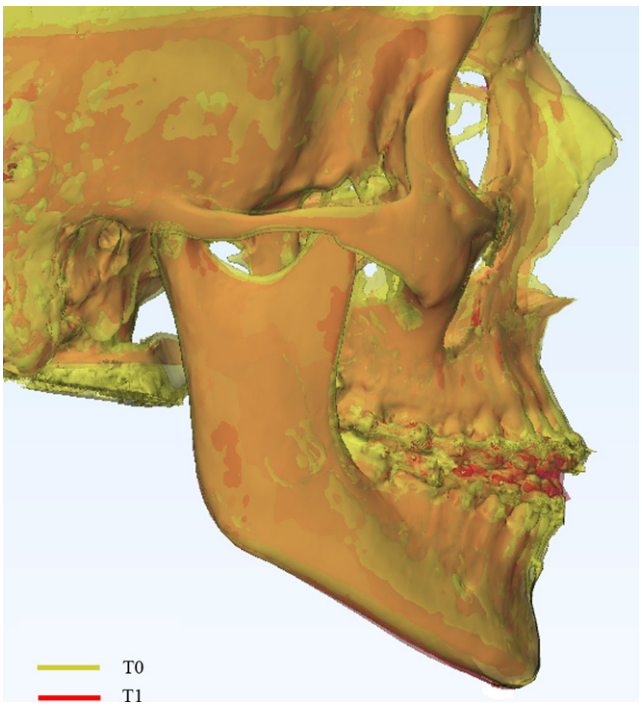

Fig. 7 Superimposition of the cone-beam computed tomography (CBCT) images
Abb. 7 Überlagerung der DVT(digitale Volumentomographie)-Aufnahmen

CBCT findings

According to the dental parameters measured on 3D images, in the piezocision group, maxillary and mandibular incisors (1.28 mm and 1.96 mm, respectively), canines (0.7 mm and 1.4 mm, respectively), mandibular premolars (0.46 and 0.66 mm), and first molars (0.5 and 0.45 mm) were extruded (Table 5). Furthermore, both maxillary and mandibular incisors (1.57 and 1.96 mm, respectively), canines, and premolars were uprighted. On the other hand, in the control group, both maxillary and mandibular incisors (1.97 and 1.4 mm, respectively) and canines were extruded but only the incisors were uprighted (1.25 mm on the maxilla and 0.53 mm on the mandible). When the dental changes achieved with the treatment protocols were compared between the groups, only the amount of extrusion of the lower incisor was significantly higher in the piezocision group.

Discussion

Wilcko et al. were among the first to document the RAP effects on bone remodeling. They reported the onset after 1–2 months following bone injury and the lasting of the effects for 2–4 months [26, 27]. Studies regarding the effectiveness of piezocision for canine retraction showed a significantly higher rate of canine retraction by 1.5–2 times during the first 3 months [20, 21, 28]. A recent randomized clinical trial reported a reduction of 59% in the overall alignment time when piezocision was used in the correction of severely crowded lower anterior teeth after first premolar extractions [25]. However, there are also studies reporting conflicting results [23, 29]. These controversial findings might be due, for example, to sample size, differences in the surgical protocol (invasiveness of the cuts, piezocision site), orthodontic protocol (activation frequency of the mechanics or treatment method of the malocclusion such as

Table 5 Intra- and intergroup comparisons of dental parameters measured on three-dimensional images at T0 and T1
Tab. 5 Intra- und Inter-Gruppen-Vergleiche dentaler Parameter, gemessen auf dreidimensionalen Bildern bei T0 und T1

	Piezocision			Control			Piezocision vs control p^b
	T0	T1	Difference Mean ± SD (p)[a]	T0	T1	Difference Mean ± SD (p)[a]	
VERTICAL (mm)							
RP1-U1R	51.96 ± 2.72	53.23 ± 2.92	1.28 ± 1.1***	50.12 ± 3.16	52.09 ± 3.39	1.97 ± 1.42***	0.148
RP1-U3R	51.72 ± 2.74	52.51 ± 2.89	0.79 ± 0.91**	50.27 ± 3.15	51.33 ± 3.35	1.06 ± 0.97***	0.439
RP1-U3L	51.56 ± 2.35	52.26 ± 2.62	0.71 ± 0.66***	50.09±3	51.35 ± 3.27	1.26 ± 0.8***	0.052
RP1-U5R	49.81 ± 2.64	49.65 ± 2.79	–0.16 ± 0.79	48.93 ± 3.2	48.87 ± 3.15	–0.06 ± 0.96	0.760
RP1-U5L	49.6 ± 2.41	49.54 ± 2.53	–0.06 ± 0.78	48.82 ± 3.12	48.73 ± 3.4	–0.09 ± 0.87	0.910
RP1-U6R	39.09 ± 2.59	38.97 ± 2.74	–0.13 ± 0.54	36.51 ± 3.29	36.2 ± 3.71	–0.3 ± 0.78	0.474
RP1-U6L	38.84 ± 2.46	38.7 ± 2.43	–0.14 ± 0.92	36.61 ± 2.89	36.68 ± 2.83	0.07 ± 0.56	0.448
RP1-U7R	37.1 ± 2.84	36.74 ± 2.83	–0.36 ± 0.82	33.75 ± 3.13	33.77 ± 3.29	0.02 ± 0.92	0.251
RP1-U7L	36.45 ± 2.7	36.17 ± 2.81	–0.28 ± 0.83	33.52 ± 3.24	33.77 ± 3.45	0.25 ± 0.74	0.074
RP3-L1R	41.01 ± 3.37	42.97 ± 3.27	1.96 ± 0.72***	41.86 ± 3.86	43.26 ± 3.86	1.4 ± 0.75***	0.048*
RP3-L3R	39.46 ± 3.22	40.89 ± 3.33	1.43 ± 0.82***	40.22 ± 3.66	41.58 ± 3.85	1.35 ± 0.96***	0.828
RP3-L3L	39.74 ± 3.37	41.21 ± 3.16	1.47 ± 0.69***	40.19 ± 3.77	41.41 ± 3.8	1.22 ± 0.84***	0.383
RP3-L5R	35.12 ± 3.39	35.59 ± 3.69	0.46 ± 0.66**	35.73 ± 3.47	35.8 ± 3.96	0.07 ± 1.61	0.386
RP3-L5L	34.95 ± 3.2	35.61 ± 3.15	0.66 ± 0.5***	35.32 ± 3.52	35.6 ± 3.65	0.29 ± 1.13	0.259
RP3-L6R	23.39 ± 3.9	23.89 ± 3.71	0.5 ± 0.88*	22.57 ± 3.52	22.82 ± 3.72	0.25 ± 1.31	0.548
RP3-L6L	23.47 ± 3.31	23.92 ± 3.31	0.45 ± 0.74*	22.23 ± 3.36	22.29 ± 3.54	0.07 ± 0.93	0.227
RP3-L7R	19.85 ± 4.19	19.58 ± 4.48	–0.27 ± 0.96	17.6 ± 3.79	17.55 ± 3.98	–0.05 ± 1.31	0.598
RP3-L7L	20.39 ± 3.53	20.36 ± 3.7	–0.04 ± 0.97	17.86 ± 2.88	17.39 ± 2.96	–0.46 ± 0.9	0.221
SAGITTAL (mm)							
RP2-U1R	92.9 ± 7.62	91.34 ± 7.38	–1.57 ± 1.13***	93.94 ± 6.15	92.7 ± 5.9	–1.25 ± 0.82***	0.375
RP2-U3R	83.93 ± 7.31	83.13 ± 7.45	–0.8 ± 1.03*	85.29 ± 5.36	85.23 ± 5.31	–0.06 ± 1.24	0.091
RP2-U3L	84.15 ± 6.64	83.36 ± 6.96	–0.78 ± 1.09*	85.13 ± 5.48	84.83 ± 5.58	–0.3 ± 1.24	0.267
RP2-U5R	70.48 ± 6.65	69.9 ± 6.51	–0.59 ± 0.72**	71.99 ± 5.12	71.99 ± 5.06	–0.01 ± 1.25	0.132
RP2-U5L	70.6 ± 6.62	70.06 ± 6.46	–0.54 ± 0.85*	71.21 ± 4.53	70.91 ± 5.09	–0.3 ± 1.28	0.558
RP2-U6R	61.97 ± 5.79	61.85 ± 5.68	–0.11 ± 0.57	62.04 ± 5.02	62.17±5	0.36 ± 0.76	0.064
RP2-U6L	61.81 ± 5.77	61.78 ± 5.67	–0.02 ± 0.63	62.14 ± 5.26	62.44 ± 5.24	0.29 ± 0.76	0.228
RP2-U7R	53.66 ± 6.85	53.35 ± 6.75	–0.32 ± 0.83	54.27 ± 3.74	54.33 ± 3.46	0.06 ± 0.91	0.241
RP2-U7L	52.66 ± 5.23	52.58 ± 5.27	–0.08 ± 0.74	53.81 ± 3.87	54.04 ± 3.97	0.23 ± 0.78	0.270
RP4-L1R	60.02 ± 6.99	58.06 ± 6.71	–1.96 ± 1.39***	57.53 ± 5.25	56.53 ± 5.02	–1 ± 1.39**	0.070
RP4-L3R	55.17 ± 6.73	53.41 ± 6.51	–1.76 ± 1.33***	51.49 ± 5.29	50.86 ± 5.21	–0.63 ± 1.92	0.073
RP4-L3L	54.89 ± 6.78	53.61 ± 6.6	–1.28 ± 1.51**	53.23 ± 4.94	52.93 ± 5.51	–0.3 ± 1.58	0.092
RP4-L5R	43.41 ± 6.11	42.49 ± 5.83	–0.92 ± 1.28*	39.25 ± 5.43	39.02 ± 5.18	–0.23 ± 1.65	0.213
RP4-L5L	43.12 ± 6.58	42.17 ± 6.34	–0.94 ± 1.34*	41.64 ± 4.51	41.47 ± 4.84	–0.17 ± 1.57	0.156
RP4-L6R	36.99 ± 5.98	36.63 ± 5.59	–0.36 ± 1.42	33.15 ± 5.77	33.20 ± 5.21	0.05 ± 1.84	0.501
RP4-L6L	36.29 ± 6.55	35.72 ± 6.35	–0.57 ± 1.19	35.09 ± 5.29	35.09 ± 5.31	0.00 ± 1.94	0.336
RP4-L7R	27.14 ± 6.35	26.7 ± 5.92	–0.45 ± 1.48	23.38 ± 6.13	23.71 ± 5.48	0.33 ± 1.72	0.196
RP4-L7L	25.68±7	25.23 ± 6.59	–0.45 ± 1.34	25.6 ± 5.55	26.08 ± 5.07	0.48 ± 1.73	0.111

SD standard deviation, *T0* before use of vertical elastics, *T1* after correction of the open bite
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$
[a]Paired-samples t test
[b]Student t test

alignment of the crowded anterior teeth, canine distalization, en masse retraction), and measuring methods. Thus, the aim of the present study was to investigate the effects of piezocision in the course of open-bite correction.

In most of the open-bite patients, the palatal plane is rotated in counterclockwise direction and upper posterior alveolar height is increased [30–32]. Therefore, intrusion of the upper posterior teeth can reverse this situation. Zygomatic miniplates are reported as effective anchorage units

to correct skeletal anterior open-bites [31]. There are also case reports in the literature explaining how the corticotomy procedure was applied to achieve efficient molar intrusion [10, 11]. Mostafa et al. [12] performed corticotomy cuts between the roots of the upper anterior teeth and the open-bite patients were instructed to use vertical elastics between the upper and lower anterior teeth to increase the overbite. They claimed that the amount of upper incisor extrusion exceeded the lower incisor extrusion since the corticotomies initiated the regional accelerated phenomenon (RAP) around the upper teeth [13]. However, due to the need of flap surgery and suturing, the corticotomy procedure is more invasive than piezosurgery. Bleeding from the surrounding soft tissues is also reduced due to less vibration and noise in piezocision.

The treatment effects of curved archwires and anterior elastic mechanics were reported as extrusion and retraction of upper and lower incisors, change of the occlusal plane inclinations and distal uprighting of posterior teeth [4, 6, 7]. The aim of this study was to evaluate if the piezocision procedure around the upper molars can enhance the possible intrusion effect on upper posterior teeth or at least maintains the vertical positions while the upper and lower incisors are being extruded with the elastics.

Former studies, except Erdem and Kucukkeles [9], used either cephalometrics [4, 6, 7] or oblique cephalograms [33] in which superimpositions of right and left sides can mislead the results [4, 34]. Even though the oblique cephalograms is more useful since it captures two different images for the right and left side, none of them is as accurate as CBCT measurements [35]. In addition, true molar intrusion can be evaluated only when the center of resistance of the molar is used as the reference point to quantify the vertical movement of the molar. Using the cusps or apices would lead to incorrect results since the technique caused distal tipping of posterior teeth [36]. These limitations were solved by having the CBCT images in the present study.

There was a statistically significant difference between the groups regarding the duration of open-bite closure. However, it was just one-month difference and patients who underwent piezocision might have used the elastics more intensively because they understood the severity of the malocclusion due to being subjected to some kind of surgery from their point of view.

According to the dental changes observed in this study, the maxillary and mandibular incisors were considerably extruded and retruded in both groups. The extrusion amounts in the piezocision group were 1.28 mm and 1.96 mm for the upper and lower incisors, respectively. These changes were 1.97 mm and 1.4 mm in the control group. Upper and lower incisors had 1.57 mm and 1.96 mm of retrusion in the piezocision group while 1.25 mm and 1 mm of retrusion were seen in the control group, respectively. Overbite increased by almost 4.5 mm in both groups. The only significant difference between the groups was the increased extrusion of the lower incisors in the piezocision group which caused a statistically significant counterclockwise rotation of the lower occlusal plane angle in this group. Similar changes for the anterior teeth were observed by studies using both the MEAW technique and the modified technique [4, 6–9, 33].

Although intrusion of the upper molars was the main target, the open-bite correction was achieved by extrusion of the incisors in both groups. On the other hand, a vertically stable position of the upper posterior teeth was seen in both groups. However, Kucukkeles et al. [7] and Chang and Moon [37] reported significant extrusion (1.11 mm and 1.41 mm, respectively) of the upper posterior teeth.

Differing from the control group, distal tipping of the canines and premolars and extrusion of the lower premolars and first molars were observed in the piezocision group. The lower posterior teeth were extruded due to the vertical elastics use while they were uprighted. Although these movements in the piezocision group were statistically significant, they were insignificant clinically due to small amounts (ranging between 0.45 and 0.66 mm) and also insignificant when the groups were compared. Even though lower posterior teeth extruded, the lower occlusal plane angle which normally was expected to rotate clockwise in this instance decreased significantly (3.07°). This was due to lower incisor extrusion being larger than molar extrusion in this group.

The only study that reported significant intrusion of maxillary molars was performed by Kim et al. [38]. With the MEAW technique, they reported 0.66 mm intrusion which could be a misleading result of cephalometric analysis due to distal tipping of molar cusps and superposition of the right and left sides. In addition, maxillary second or third molars were extracted in most of the cases in their study and they reported that the treatment results were stable at a 2-year follow-up. However, in the present study differently from the study of Kim et al. [38], no tooth extractions were performed. Therefore the long-term stability of the modified MEAW technique should also be monitored.

According to the results of a recent systematic review [39], there is only limited evidence that minimally invasive techniques for accelerating tooth movement are effective; however, the results of this meta-analysis might have been affected by the use of different archwires, inconsistent forces in moving the teeth, measuring methods and operative methods in each study. It is also important on which site the piezocision was performed since the acceleration effect in the maxilla was reported to be more immediate and lasted longer compared to that in the mandible due to the higher density of mandibular bone [22]. The present studies related to accelerating tooth movement mostly focused on canines and incisors and there is no research on

other teeth. As it was the first study to examine the effects of piezocision on intrusion movement, there is no study to compare with our results.

Piezocision is only capable of starting a regional RAP effect. However, the movement of intrusion is not just localized on the buccal region. Therefore, piezocision can be recommended to be performed additionally on the palatal side of the alveolar bone for future studies. Also, it has been reported that the effectiveness of the piezocision lasted 3 months after surgery and this progressive and transient acceleration might be explained by the initiation and the expiration of the RAP effect [12, 19, 24]. The risk of premature fusion of piezocision cuts is higher than that for decortications since the knives used for piezocision technique are thinner than the burs. As it was reported in a recent systematic review, acceleration of tooth movement during canine retraction was four times faster with the corticotomies and only twice as fast with the piezocision when compared with the conventional method [40]. Therefore, the duration of regional acceleration seems to be limited in piezocision technique and so performing a second stage of piezocision after 3 months might be suggested although it has not been investigated yet.

Charavet et al. [24] suggested placing the archwires 1–2 weeks before the surgery to trigger tooth displacement, perform the cuts at least 3 mm in depth and 5–8 mm in length and monitor the patient at 2-week intervals to activate the mechanics if possible. In the present study, the piezocision was performed on the same day with the wire insertion. The depth of cuts was relevant; however, the length of the cuts was shorter as it was only 4 mm which might be the reason for the differences since the magnitude of the RAP effect is highly dependent on the invasiveness of the procedure [13, 26, 41, 42]. The gingival incision was made long enough for the tip of the piezosurgery knife to enter. Longer gingival incisions may require suturing or may cause scarring of the gingiva which may result in an unesthetic gingival appearance. There was no need to activate the mechanics every 2 weeks since the curved archwires were already active and the intraoral elastics were changed daily.

Conclusion

- Open-bite closure was significantly faster in the piezocision group.
- The correction was achieved mainly by extrusion and retrusion of the incisors and maintaining upper molar positions vertically stable in both groups.
- No evidence was found to support the claim that the piezosurgery technique is an efficient way for upper molar intrusion.
- No molar intrusion was observed in either group.
- The efficiency of piezosurgery technique for molar intrusion in open-bite cases should be further investigated with an additional palatal surgical approach and also repeated piezosurgeries can be suggested.
- The long-term stability of the treatment results in both groups should be monitored.

Compliance with ethical guidelines

Conflict of interest H.N. Yilmaz, E. Alakus, B. Erdem and N. Kucukkeles declare that they have no competing interests.

Ethical standards For this article no studies with human participants or animals were performed by any of the authors. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by the Marmara University Ethics Committee (approval no. 2019-354). Written informed consent to participate was obtained from the patients or parents in case of minor. Written informed consent for publication was obtained from the patients or parents in case of minor.

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