

Treatment effects and biomechanical analysis of TMA spring appliance

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Background/Aim

Among Angle's classification, skeletal class III is the most difficult to treat. Treatment using the TMA spring intraoral appliance was investigated in the late mixed dentition and showed desirable effects. The present work aimed to investigate, biomechanically, the TMA spring appliance in the early mixed-dentition stage with specifically outlined force direction, duration, and magnitude in order to provide solid results that can be relied upon clinically.

Patients and methods

The sample consisted of 20 patients with an age range 8–10 years and an average of 8.6 years. Lateral cephalograms were taken and analyzed before treatment (T1), posttreatment (T2), and postretention (T3). The patients were instructed to wear the TMA spring appliance 12–16 h/day for 9 months, followed by 6 months of retention. The appliance delivered a force of 400 g/per side as measured with the force gauge.

Results

Comparing T1–T2 and T1–T3, there was a significant difference between sexes in points U6/S perpendicular; $P=0.013$ and $P=0.0159$, SNA ($P=0.0122$, $P=0.0371$), and ANB ($P=0.0491$) at T1–T2. There was a significant difference in the whole sample for all the skeletal, dental, and soft-tissue measurements; P value less than 0.05, regarding treatment and retention changes.

Conclusions

The TMA spring appliance enhanced the cooperation of the patients, resulted in forward movement and clockwise rotation of the maxilla. Mandibular clockwise rotation and dentoalveolar changes also contributed to the overall correction of class III.

Keywords:

Class III treatment, face mask, maxillary protraction, prevalence of Class III, stability of Class III treatment

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Introduction

Among the different Angle's classes, the most difficult to treat is class III [1]. It varies from skeletal mandibular prognathism and/or maxillary retrusion, or could be purely dentoalveolar in nature [2]. The reported prevalence of class III is variable among different populations, with the highest rate in Asians and a considerably high rate in the Egyptian population; 11.38% [3–7].

The skeletal component of class III in 30–40% of the cases is due to a degree of maxillary retrusion [8]. Several intraoral and extraoral appliances were designed for maxillary protraction and to provide some degree of control over mandibular growth. Intraoral appliances are variable in design, ranging from Bionator III, Frankel III, and Eschler appliance, which produce more unwanted dentoalveolar rather than skeletal effects [8–11], to a combination of an intraoral component and a face mask, or skeletal anchorage [12–14]. On the other hand, extraoral appliances, including face masks, chin

cups, or a combination of face mask and skeletal anchorage, presumably, provide better orthopedic effects; however, being extraoral and unesthetic presented a cooperation and acceptance problem among patients [15]. Further, the effectiveness of face mask was rather controversial throughout the literature, varying from no change to a considerable maxillary protraction; which was contributed to the use of magnitude, direction, and duration of force parameters that were not supported by the literature [16].

The success of treatment depends mainly on the severity of malocclusion and the treatment timing. Mild-to-moderate class III cases treated orthopedically during the deciduous or early mixed dentition, present the best-result outcome [8,16–19].

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Looking at the data reported in the literature, it seemed that there was a need for a noninvasive and esthetic appliance that could induce effective orthopedic class III treatment results, with clearly outlined clinical parameters for use. The TMA spring intraoral appliance was initially introduced and investigated on late mixed-dentition patients, it showed desirable skeletal and soft-tissue changes and a general acceptance by the patients; esthetically [15].

Accordingly, it was desirable to investigate, biomechanically, the TMA spring appliance in the early mixed-dentition stage with specifically outlined force direction, duration, and magnitude in order to provide solid results that can be relied upon clinically.

Patients and methods

Patients

The sample consisted of 20 patients (13 males and 7 females), attending a private practice for orthodontic treatment. The sample-size calculation showed that this was the minimal number to obtain a statistical power of 80% and a significance level 5% with 20% dropout ratio. The patients' age ranged from 8 to 10 years, and an average of 8.6 years.

The selection criteria were such that functional clinical examination excluded pseudo class III cases, and cephalometric measurements showed skeletal class III with maxillary deficiency ($ANB > 0^\circ$, Wits > -1) [15,20]. All the participants had a symmetrical occlusion and were free from any systemic diseases or syndromes and had not received previous orthodontic treatment.

Ethical approval

This study was carried out in accordance with the principles of the Declaration of Helsinki and all the patients' parents or guardians signed informed consents. The ethical approval was obtained from the Ethical Committee of Misr University for Science and Technology, under registration number 2021/0003.

Study design

Lateral cephalograms were taken pretreatment (T1), posttreatment (T2), and postretention (T3) and were traced and superimposed by the same investigator. The measurements were repeated after 1 month for 10 of the cephalograms. Interclass correlation coefficient was above 0.92, which indicated reliability of measurements.

Methods

The reference planes used are shown in Fig. 1.

Skeletal measurements

Angular measurements:

SNA, SNB, ANB, SN/MP (Sella-Nasion/Mandibular plane), SN/PP (Sella-Nasion/Palatal plane), and Y axis (S-Gn/FH).

Linear measurements:

A/NaV (A/Nasion vertical), where nasion vertical is a perpendicular line from nasion, B/NaV (B/Nasion vertical), and Wits analysis.

Dental measurements

Angular measurements:

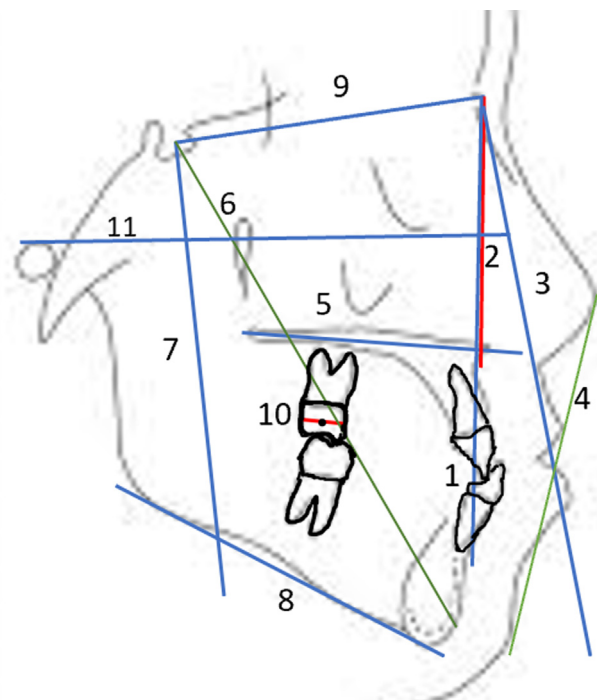
U1/SN: Upper incisor/Sella–Nasion.

L1/MP: Lower incisor/Mandibular plane.

Linear measurements:

U1/NA, L1/NB, and U6/S perpendicular, which is the perpendicular distance from the molar centroid to a perpendicular line on SN from S point, where the centroid is the midpoint on a line joining the most convex distal and mesial points on the crown.

Figure 1



Reference planes used: 1: NB, 2: NA, 3: NaV, 4: E-line, 5: PP, 6: Y axis (S-Gn/FH), 7: S perpendicular, 8: MP, 9: SN, 10: centroid, 11: FH.

Soft-tissue measurements

ULip/E-line (Upper lip/E-line), LLip/E-line (Lower lip/E-line).

Appliance design, insertion, and activation

The TMA spring appliance consists of upper and lower splints (Fig. 2). The upper splint is retained in position using Adam's clasps on the first permanent molars and labial bow, a 45-mil auxiliary tube is embedded in the acrylic mesial to the first permanent molar. The splint is retained in place using Adam's clasps and acrylic capping covering third of the lower incisors. After the construction of the splints, the upper and lower study models were connected using a wax bite in centric occlusion and mounted on an articulator. A 0.036' TMA spring was designed with two-and-a-half turn helix, on the mounted casts, to join the upper and lower splints delivering a constant force of 400 g/side; when active [16]. The force magnitude was measured using

Correx force gauge (Haag-Streit, Bern, Switzerland). The spring has two arms: the lower arm is embedded in the acrylic of the lower splint and is parallel to the lower occlusal plane, while the upper arm is designed to be 45° above the maxillary occlusal plane with a bend to facilitate its insertion in the auxiliary tube. Both splints were assembled outside the mouth and then inserted.

The patients and their guardians were educated on how to assemble the appliance and insert it; where the lower splint was to be inserted first followed by backward sliding of the upper splint. They were instructed to wear the appliance for 12–16 h/day [16,17,21,22] and keep a daily record of their wear. The duration of treatment was 9 months followed by a 6-month retention period using the same appliance after its passivation. All the patients signed an informed consent prior to the start of treatment.

The patients were recalled after 1 week from the commencement of treatment to check for any problems encountered or complaints, then the patients were checked on a monthly basis. Every visit, the ease of insertion and removal of the appliance by the patient was observed to account for compliance [23,24]. The force magnitude was also measured using the force gauge; every visit.

Figure 2

TMA spring appliance intraorally.

Statistical analysis

Statistical analysis was done using IBM SPSS, version 23 (IBM, Armonk, New York, USA). Means and SDs were calculated. The data showed nonparametric distribution when tested for normality using Shapiro–Wilk test. Accordingly, χ^2 test was used

Table 1 Comparison between males and females for each point at T1, T2, and T3

	T1		P value	T2		P value	T3		P value
	Female	Male		Female	Male		Female	Male	
A/NaV (mm)	-4.4±3.5	-4.5±4.4	1.00	-1.6±2.2	-1.5±4.4	0.7112	-1.3±2.4	-0.9±3.9	0.393
ANB	-3.1±3.6	-4.3±1.4	0.3168	-0.5±2.6	-0.1±1.8	0.6293	-1.2±5.0	-0.4±1.6	0.6556
B/NaV (mm)	-1.8±1.4	-1.0±3.3	0.4988	-2.1±1.8	-1.7±2.6	0.717	-1.6±1.7	-1.1±2.5	0.6606
L1/MP	91±2.5	91.7±2.9	0.5771	87.7±2.2	88.6±2.3	0.4237	88.9±2.4	89.6±2.2	0.4737
L1/NB (mm)	4.2±0.8	4.5±1.1	0.5675	2.8±0.6	3.1±1.0	0.4644	3.1±0.6	3.6±1.1	0.4697
LL/E-line (mm)	-2.4±0.6	-2.6±0.8	0.4137	-3.1±0.4	-3.5±0.7	0.1881	-2.9±0.3	-3.2±0.8	0.1899
MP/SN	29.3±1.9	30.1±2.4	0.5746	32.4±1.3	32.3±2.0	0.8091	31.7±0.8	31.6±1.8	0.7747
PP/SN	8.3±2.4	9.3±2.3	0.3781	9.6±2.1	10.5±2.0	0.2931	9.9±2.1	10.9±2.0	0.186
SNA	76.9±2.7	76.7±2.8	0.8734	78.1±2.3	79.2±2.9	0.4262	78.7±1.8	79.9±2.6	0.2479
SNB	80.1±1.3	81.0±3.3	0.6612	78.6±0.8	79.2±3.0	0.811	79.9±4.1	80.2±2.8	0.3393
U1/NA (mm)	4.6±0.5	4.3±0.9	0.3439	6.6±0.8	6.2±1.4	0.3919	5.4±1.1	5.2±1.0	0.6563
U1/SN	107.8±2.7	108.5±2.4	0.6303	111.9±3.4	113±2.8	0.5228	110.6±3.3	111.6±2.9	0.4495
U6/S perpend (mm)	32.9±1.5	30.1±4.8	0.3169	34.9±1.2	31.4±4.5	0.1297	34.1±1.2	30.6±4.5	0.1121
UL/E-line (mm)	-4.7±0.7	-5.0±0.8	0.4854	-2.6±0.6	-2.9±1.0	0.4328	-3.00±0.6	-3.3±1.3	0.6837
WITS (mm)	-3.3±1.0	-3.4±1.0	0.8101	-1.1±0.7	-0.8±0.6	0.2736	-0.9±0.3	-0.5±0.7	0.4603
Y axis	58±1.3	59.5±2.0	0.0811	60.3±1.4	61.9±1.8	0.0829	59.1±1.1	60.5±1.5	0.0451*

All data are expressed as mean±SD *Significant difference at P value less than 0.05, using χ^2 test.

to compare between males and females for each point and Wilcoxon signed-rank test was used to compare between T1, T2, and T3; the significance level was set at P value less than 0.05.

Results

Means and SDs were calculated and χ^2 test was used to compare between males and females for each point. The results showed no significant difference between both sexes at T1, T2, or T3, except for the Y axis at T3; $P=0.0451$ (Table 1).

Wilcoxon signed-rank test showed that there was a significant difference between males and females at T1–T2 and T1–T3 regarding points U6/S perpendicular ($P=0.013$ and 0.0159), SNA ($P=0.0122$, 0.0371), and ANB ($P=0.0491$) at T1–T2; Table 2. The same test was also used to evaluate the treatment and retention changes observed (T1–T2, T2–T3, and T1–T3) for all the dental, skeletal, and soft-tissue parameters measured. The results were statistically significant in almost all of the parameters at different times; T2 and T3 shown in Table 3, while they were insignificant regarding B/Nav at T1–T2 and T1–T3, SNB at T1–T3, and Wits at T2–T3; $P=0.057$, 0.9239 , 0.0826 , and 0.1954 , respectively.

Discussion

Orthopedic correction of skeletal class III has always presented a challenge for clinicians due to the varied etiological factors involved, along with the difficulties

presented in controlling mandibular growth. There is an increasing acceptance about the role that maxillary deficiency plays in the etiology of class III [22]. Kambara's [25] animal study showed remodeling at the maxillary sutures and maxillary tuberosity with forward maxillary movement and a high degree of cellular activity at the sutures during early treatment.

The optimal treatment time for such cases is an important factor for the success of treatment; it has been suggested that treatment as early as the deciduous dentition or early mixed dentition provided the best results [8,17,18]. Nevertheless, Merwin *et al.* [26] reported 52% skeletal maxillary movement in patients less than 8 years and 63% in those above 8 years [27,28]. Combining the information, it seemed to be optimal for the study to choose patients in the early mixed dentition, but not under 8 years.

There were no clearly defined force levels reported in the literature to be more effective than others [16]. A systematic review by Yepes *et al.* [16] showed that medium forces between 300 and 400 g provided more effective maxillary protraction with some differences in the results owing to other variables involved such as the duration of treatment. Many studies prescribed maxillary protraction for 12–16 h/day for 9–12 months [17,21,22,29–32]; the force levels and duration used were, hence, derived from these data.

The variable problems associated with the use of extraoral or intraoral maxillary protraction appliances have called for the development of an appliance that attempts to correct some or all of

Table 2 Comparison between males and females after treatment and after retention (T1, T2, and T3)

	T1–T2		P value	T1–T3		P value	T2–T3		P value
	Female	Male		Female	Male		Female	Male	
A/Nav (mm)	-2.86 ± 1.35	-3.00 ± 1.58	1	-3.14 ± 1.80	3.62 ± 2.10	0.6893	-1.00 ± 1.00	-0.54 ± 0.59	0.4603
ANB	2.69 ± 1.55	4.23 ± 1.36	0.0491*	1.91 ± 3.59	3.92 ± 1.85	0.2169	1.14 ± 2.04	0.15 ± 0.66	0.5241
B/Nav (mm)	0.36 ± 0.94	0.62 ± 1.49	0.3741	0.14 ± 1.46	0.08 ± 1.29	0.4719	-1.64 ± 1.65	-0.84 ± 2.87	0.5904
L1/MP	-3.29 ± 1.11	-3.08 ± 1.12	0.6497	-2.14 ± 1.18	-2.12 ± 1.15	0.9341	0.71 ± 0.57	0.42 ± 0.81	0.379
L1/NB (mm)	-1.41 ± 0.72	-1.42 ± 0.67	0.764	-1.06 ± 0.78	-0.92 ± 0.57	0.5347	0.01 ± 0.72	0.31 ± 0.44	0.3141
LL/E–line (mm)	-0.79 ± 0.57	-0.96 ± 0.56	0.8214	0.57 ± 0.53	0.65 ± 0.52	0.8298	-0.64 ± 2.06	-0.38 ± 2.48	0.435
MP/SN	3.14 ± 1.35	2.23 ± 0.73	0.0929	2.43 ± 1.72	1.54 ± 0.88	0.2237	-0.57 ± 0.53	-0.77 ± 0.83	0.7576
PP/SN	1.29 ± 0.39	1.15 ± 0.69	0.6299	1.63 ± 0.56	1.62 ± 0.68	0.8393	0.50 ± 0.00	0.38 ± 0.30	0.1847
SNA	1.20 ± 1.03	2.46 ± 0.78	0.0122*	1.77 ± 1.44	3.23 ± 0.93	0.0371*	1.29 ± 0.95	1.31 ± 0.75	0.7403
SNB	-1.49 ± 0.89	-1.77 ± 0.73	0.3957	-0.14 ± 3.98	-0.77 ± 1.62	0.9046	1.00 ± 0.00	1.58 ± 0.81	0.2125
U1/NA (mm)	2.00 ± 0.58	1.92 ± 0.73	0.9285	0.79 ± 0.39	0.86 ± 0.51	0.6411	-1.2 ± 0.59	-1.07 ± 0.50	0.6628
U1/SN	4.14 ± 1.65	4.48 ± 1.62	0.6027	2.79 ± 1.29	3.09 ± 1.51	0.5235	-1.01 ± 0.26	-1.02 ± 0.41	0.675
U6/S perpend (mm)	2.00 ± 0.58	1.35 ± 0.55	0.0313*	1.29 ± 0.76	0.53 ± 0.48	0.0159*	-0.79 ± 0.27	-0.27 ± 0.33	0.2749
UL/E–line (mm)	2.07 ± 0.53	2.08 ± 0.81	0.8711	1.71 ± 0.70	1.69 ± 1.05	0.7169	-0.73 ± 0.39	-0.81 ± 0.25	0.6199
WITS (mm)	-2.21 ± 0.57	-2.63 ± 0.95	0.4015	-2.41 ± 0.73	-2.84 ± 1.21	0.4714	0.57 ± 1.79	0.27 ± 0.48	0.7796
Y axis	2.29 ± 0.76	2.46 ± 0.78	0.6982	1.14 ± 0.69	1.08 ± 0.76	0.8629	-0.36 ± 0.24	-0.23 ± 0.26	0.5227

All data are expressed as mean $\pm$ SD. *Significant difference at P value less than 0.05 using Wilcoxon signed-rank test.

Table 3 Change in dental and skeletal parameters after treatment T2, and after retention T3

	T1-T2	P value	T1-T3	P value	T2-T3	P value
A/NaV (mm)	-2.95±1.47	<0.0001*	-3.45±1.97	<0.0001*	-0.70±0.77	0.1133
ANB	3.69±1.58	<0.0001*	3.22±2.68	0.0002*	0.50±1.35	0.7708
B/NaV (mm)	0.53±1.30	0.057	0.00±1.32	0.9239	-1.12±2.49	0.0031*
L1/MP	-3.15±1.09	<0.0001*	-2.13±1.13	<0.0001*	0.53±0.73	<0.0001*
L1/NB (mm)	-1.42±0.67	<0.0001*	-0.97±0.63	<0.0001*	0.21±0.55	0.0004*
LL/E-line (mm)	-0.90±0.55	<0.0001*	0.63±0.51	<0.0001*	-0.47±2.29	0.001*
MP/SN	2.55±1.05	<0.0001*	1.85±1.27	<0.0001*	-0.70±0.73	0.0016*
PP/SN	1.20±0.59	<0.0001*	1.62±0.63	<0.0001*	0.42±0.24	<0.0001*
SNA	2.02±1.05	<0.0001*	2.72±1.31	<0.0001*	1.30±0.80	0.0005*
SNB	-1.67±0.77	<0.0001*	-0.55±2.60	0.0826	1.38±0.70	0.0408*
U1/NA (mm)	1.95±0.67	<0.0001*	0.84±0.46	<0.0001*	-1.12±0.52	<0.0001*
U1/SN	4.36±1.59	<0.0001*	2.99±1.41	<0.0001*	-1.02±0.35	<0.0001*
U6/S perpend (mm)	1.58±0.63	<0.0001*	0.80±0.68	0.0001*	-0.45±0.39	<0.0001*
UL/E-line (mm)	2.08±0.71	<0.0001*	1.70±0.92	<0.0001*	-0.78±0.30	0.0469*
WITS (mm)	-2.49±0.84	<0.0001*	-2.69±1.07	<0.0001*	0.38±1.09	0.1954
Y axis	2.40±0.75	<0.0001*	1.10±0.72	<0.0001*	-0.28±0.26	<0.0001*

All data are expressed as mean±SD. *Significant difference at P value less than 0.05 using Wilcoxon signed-rank test.

them. The TMA spring appliance results showed a significant increase in SNA angle and reduction of A/NaV, 2.20 and 2.95 mm, respectively, indicating forward maxillary movement. Compared with previously reported results using the TMA spring appliance [15], it could be seen that the controlled force delivered over a longer treatment period and in a younger age group led to higher values of maxillary protrusion, which were significant in males compared with females, as seen from SNA; $P=0.0122$ and ANB; $P=0.0491$. Previous results reported SNA to be 0.90 for males and 1.150 for females treated over a 6-month period [15]. The forward movement of point A was more than that reported by other studies, either using higher force levels or longer treatment periods combined with maxillary expansion [22,29,30,33], and similar to other studies using face mask combined with either expansion or corticotomy [20,21,31,34].

The TMA spring appliance was designed to contain a flexible spring 45° above the occlusal plane; delivering a constant forward and counterclockwise rotational force to a maxillary splint. The vertical force being behind the center of resistance of the maxilla and the forward force below it, caused opposite clockwise and counterclockwise moments, respectively. The resultant force was forward with a clockwise moment causing downward rotation of the maxilla as evidenced by the significant increase of the PP/SN angle. This finding was in contrast to other reported findings in which counterclockwise rotation of the maxilla was observed [22,35–37]. Celikoglu and Oktay [20] reported using the force 30° downward from the occlusal plane and near the canines to prevent

the counterclockwise rotation, while Keles *et al.* [38] showed that applying the force 20mm above the occlusal plane resulted in anterior translation without rotation. Grandori *et al.* [39] and Itoh *et al.* [40] suggested combining forward and downward force vectors to translate the maxilla with minimal rotational moments. On the other hand, Hata *et al.* [41] proposed that a force 5 mm above the palatal plane produced a combined clockwise maxillary rotation and forward movement.

The mandible showed clockwise rotation with a significant reduction in SNB and a significant increase in MP/SN. This concurred with other studies which reported that there was no hindrance of mandibular growth with class III treatment, but rather a redirection of growth in the vertical dimension. They also suggested that this type of treatment would be suitable only for patients with either normal or horizontal growth patterns [31,32,42–44].

The dentoalveolar changes showed a significant proclination of maxillary incisors accompanied by a significant mesial movement of the upper first permanent molar and a significant retroclination of the mandibular incisors that were consistent with previous studies [37,38,45–47]. There was a significant difference between males and females in the treated sample as regards the U6/SN, with the males exhibiting less forward movement of the maxillary molars than females, 1.3 and 2 mm; respectively. Although insignificant, the maxillary incisors also moved less forward in males than females, and if we look at those results together with the SNA results, being significantly higher in males; we

can assume that males showed more skeletal than dental effects. There were no significant differences between both sexes in any of the other parameters otherwise, which concurred with Sung and Baik's [18] reports. Compared with more invasive protraction devices, associated with skeletal anchorage [8,34,48,49], it seems to be inevitable to totally obscure the dentoalveolar effects. The skeletal and dental changes observed contributed to the advancement of the upper lip (2.08 mm) and retraction of the lower lip (-0.90 mm), which eventually led to enhancement of the profile similar to the reports of other studies [20,45,47]. The short-term stability of treatment results was evaluated after 6 months of retention with the passivated TMA spring appliance. The amount of skeletal and dental relapse was significantly less than the amount of correction in almost all the tested parameters. The maxillary forward growth continued at a lesser rate (1°), which contrasted with previous reports of long-term research that ranged from 0.20 to a significant relapse in SNA, leading to the reestablishment of class III growth pattern [18,44,50]. On the other hand, the results were similar to those reported by Eid *et al.* in 2013 [15] using the same appliance. The mandible continued to grow forward, during retention, at a higher rate than that reported by Eid *et al.* [15] as they used chin cup for retention which restricted further forward mandibular growth. The observed dentoalveolar relapse was consistent with other research [15,51–53], and was attributed to the release of the force system. It is worth noting that the amount of reported relapse was significantly less than the amount of correction obtained.

Overall, the TMA spring appliance produced treatment effects similar to those obtained by other noninvasive protraction devices involving extraoral face mask, chin cup, or intraoral expanders. Nevertheless, being completely intraoral provided better esthetics and was well tolerated by the patients, reinforcing cooperation with no dropouts throughout the treatment period. It also delivered continuous forces with limited activations and force decay. In addition, the biomechanical analysis showed that there was a resultant clockwise moment on the maxilla that caused its downward rotation, which could be beneficial in open-bite cases and also to compensate for the clockwise rotation of the mandible in such cases.

Conclusions

The TMA spring appliance resulted in forward maxillary movement and clockwise rotation of the

mandible. The biomechanical analysis also revealed a clockwise rotation of the maxilla, confirmed with cephalometric measurements; that could be beneficial in open-bite cases. Using a constant force of 400 g for 9 months in the early mixed dentition, resulted in skeletal correction and the dentoalveolar changes contributed to the overall correction of class III. The TMA spring appliance, being totally intraoral, enhanced the cooperation of the patients.

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Conflict of interests

There are no conflicts of interest.

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