The Multiloop Edgewise Archwire Technique: Treatment Effects and Stability in Correction of Anterior Openbite

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Abstract

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Introduction: Anterior openbite (AOB) correction is a challenge to even the most skilled clinicians. Multiloop edgewise archwire (MEAW) therapy, developed in 1967 by Dr. YH Kim, is a fixed appliance technique proposed to treat moderate to severe AOBs without orthognathic surgery. Dr. Kim has reported that correction is accomplished by distal uprighting of the crowns of posterior teeth, along with extrusion and retraction of the incisors. However, his and other published studies on the technique are retrospective case series with inconsistent findings regarding the mechanisms of correction. This study incorporates a retrospective cohort design to investigate the dental and skeletal changes that occur with MEAW compared to conventional fixed appliances (FA), as well as to MEAW in conjunction with temporary anchorage devices (MEAW-TADS or TADs).

Methods: Clinicians proficient in the MEAW technique contributed records for consecutively treated non-growing AOB patients. One group of subjects was treated by a clinician with the traditional MEAW technique, and another group of subjects, treated by another provider, consisted of patients treated with MEAW in conjunction with maxillary TADs. A matched control group consisted of AOB subjects treated by multiple providers using FA. Lateral cephalogram landmarks were identified and analyzed in order to compare initial characteristics and treatment changes in the three groups. The Photographic Openbite Severity Index was used to assess stability of treatment using intraoral frontal photographs. Linear regression was used to compare pre- and post-treatment values and changes between groups, and Fisher's exact test and logistic regression were used to compare stability.

Results: The MEAW and FA groups consisted of 33 subjects, while the MEAW-TADs group comprised 15 subjects. The mean pre-treatment (T1) ages were 29.5 years for MEAW, 32.4 years for FA, and 25.6 years for the MEAW-TADs group. The majority of the patients were female. The mean T1 openbite was 2.6 mm, 2.2 mm, and 5.4 mm for the MEAW, FA, and MEAW-TADs groups, respectively. Treatment success, as defined by positive overbite on the post-treatment (T2) lateral cephalogram, was achieved in 100% of MEAW, 97% of FA, and 93% of the MEAW-TADs sample. During treatment, upper and lower incisors extruded and retroclined in all groups, although lower incisor retroclination did not reach statistical significance in the FA group. Maxillary molar vertical position and anterior facial height were significantly decreased only in the MEAW-TADs group. In the MEAW and FA subjects only, mandibular first molars extruded significantly. Upper first molar angulation (U6-SN) showed significant distal

crown tipping in the MEAW and MEAW-TADs groups. Lower first molar crowns exhibited distal tipping in all 3 groups. Follow-up photos were only available for a subset of the subjects, limiting the assessment of stability.

Conclusions: The following conclusions can be made from this study:

1. Treatment success rates were high in all three treatment groups.
2. Incisors exhibited a pattern of extrusion and retroclination in all groups.
3. The dental and skeletal effects seen in the MEAW and FA groups were similar, except MEAW patients exhibited greater distal crown tipping of the first molars and more lower incisor extrusion. Molar vertical positions were minimally changed in the MEAW and FA groups.
4. Only the MEAW-TADs group demonstrated significant maxillary molar intrusion and reduction of AFH. This group also had significantly more upper incisor retraction than MEAW alone.

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INTRODUCTION

Openbite is defined as a lack of vertical overlap between opposing teeth with the remaining teeth in maximum intercuspation.[1–3] The openbite may be present in the anterior or posterior dentition. This paper will focus solely on anterior openbite (AOB) and uses the term AOB and openbite interchangeably. A 1973 survey of 7,400 American children between the ages of 6 and 11 found a prevalence of anterior openbites in 4% of Caucasians and 16% in African Americans,[3] and more recent publications estimate a frequency between 1.5%[4] and 6%[5–7]. Since AOB is widely considered one of the most challenging malocclusions to treat, it is imperative that all orthodontists not only understand the etiology and prevention of anterior openbite, but also options for AOB correction.

Three main etiologic factors causing AOB are nonnutritive sucking or chewing, such as on a digit, pacifier, or pen; abnormal tongue size and function to include posturing and thrusting; and a hyperdivergent maxillo-mandibular growth pattern.[8] Other less common contributing factors may be condylar resorption, total nasal obstruction, and muscle weakness (ie. muscular dystrophy).[8–10] AOB is multifactorial in nature and there is great diagnostic challenge in determining which of these factors contribute to the anterior openbite for a particular patient. Determining the etiology is important in treatment planning, as it should be addressed, if possible.

Conventional full fixed appliances (FA) are one non-surgical option that may be utilized to correct an AOB. This treatment is not a one-size-fits-all option for any openbite patient, however. Patients with inadequate incisor display may benefit most from FA treatment where extrusion of the anterior dentition is desirable.[11] However, "the maxillary incisor segment often is reasonably well positioned relative to the upper lip" making incisor extrusion an undesirable side effect of conventional orthodontic treatment.[12] T-W Kim and H Kim[13] advise caution and a thorough workup when treatment planning to avoid mechanics that may result in excessive gingival display. Thus, Subtelney and Sakuda[2] warn that any orthodontist is bound to face many failures in treatment if he or she feels that the only solution for an anterior openbite is archwires and vertical elastics.

Growth modification can be an ideal intervention for skeletal discrepancies in growing patients, but proves very difficult as "vertical facial growth is the last to stop" and such treatment would endure for "inordinately long periods" to outlast growth[12].
Non-growing patients with a skeletal AOB are typically recommended surgical intervention. Providers and patients alike take pause before considering a surgical treatment option due to the increased cost, surgical comorbidities, and discomfort of the procedures. In 1987 Dr. YH Kim declared that with an understanding of the origins of openbites and dynamics of orthodontic mechanotherapy, AOBs could be treated "with a high degree of success and stability without surgical intervention."[14] Dr. Kim introduced the Multiloop Edgewise Archwire (MEAW) technique, using specialized wires and mechanics with a standard edgewise appliance system. He described it as a series of horizontal and vertical loop components in archwires that serve to reduce the load/deflection rate and provide horizontal and vertical control, respectively (Figure 1[15]).

The vertical loop segments serve as breaks between the teeth to allow more individual tooth control. He asserted that the technique can be applied to different malocclusions including openbites or deep bites in any Angle classification of dental occlusion. However, in that paper and in later publications, Dr. YH Kim has focused on the technique's efficacy in openbite treatment. In AOB treatment, a series of tipback bends in the posterior cause the archwires to have an exaggerated curve of Spee in the maxilla and a reverse curve in the mandible. Alone, these wires would apply an intrusive force on the incisors, worsening the openbite. To prevent this, the use of anterior vertical elastics are essential full-time.

Figure 1. Left: Photograph of an example multiloop edgewise archwire prepared with boot loops between all teeth posterior to the lateral incisors bilaterally. Accentuated maxillary and reverse mandibular curve of Spee had been added into each wire.
Right: Photograph of the MEAW in place with anterior vertical elastics the patient is instructed to wear full time.[16]

It is worth noting that the largest study to date on the MEAW technique is a retrospective case series published by the developer of the technique, Dr. YH Kim, in 2000. This study[15] consisted of 55 patients with 27 of the original sample assessed for 2-year stability. The mechanisms of the MEAW technique reported comprised of distal uprighting of posterior teeth and extrusion and uprighting of the incisors causing convergence of the occlusal planes to close the AOB.[15] Chang and Moon[17] described AOB MEAW treatment success in 16 Korean, young adults via incisor extrusion/retraction, uprighting of molars, and intrusion of mandibular second molars. Endo et al.[18] studied MEAW in 21 Japanese females and reported upper and lower incisor uprighting and extrusion along with bodily retraction of upper incisors. The study also found that upper second molars and the entire lower posterior segments extruded causing downward and backward rotation of the mandible, an unfavorable side effect in AOB correction. Deguchi et al. corrected AOB in 15 non-growing women with a mixed sample of MEAW or accentuated curve archwires. Separate groups were not outlined and results of the whole sample together included primary effects of incisor extrusion and the same clockwise mandibular rotation as seen in Endo et al.'s study.[18,19] Other case series found in the literature have much smaller samples.[20,21]

Based on the articles cited above, the literature is mixed regarding the treatment effects of MEAW, and little has been published on stability associated with this technique. The current project aims to investigate treatment effects, as well as success and stability rates, in a moderately-sized sample of adult MEAW cases. The results will be compared to a matched group treated with FA alone and a third group treated with the MEAW technique in conjunction with temporary anchorage devices (MEAW-TADs).

This project aims to characterize the treatment effects of the MEAW technique, thereby assisting clinicians as they plan treatment for anterior openbite patients.

Aims

1) Compare the success rates of AOB treatment with fixed appliances and MEAW to a) fixed appliances (FA) alone, and b) fixed appliances with MEAW and TADs (MEAW-TADs).
2) Characterize the mechanism of correction of AOB with MEAW, FA, and MEAW-TADs.
3) Assess the stability of openbite correction in the three treatment groups mentioned previously, using the Photographic Openbite Severity Index (POSI) analysis.[22]

Materials and Methods

Sample

This was a retrospective cohort study of 3 groups of anterior openbite patients treated with different techniques. The first group was treated by one private practitioner in the United States who is proficient in the MEAW technique. A comparison group of patients matched for age, sex, severity of initial openbite, initial mandibular plane angle, and extractions as a component of treatment treated with fixed appliances only (FA), and were selected from deidentified patients from the University of Washington Department of Orthodontics' records. This group was chosen to represent the typical effects of fixed appliances without MEAW. A third group of patients was treated by one experienced provider at Seoul National University, with each patient receiving MEAW, FA, and TADs. This group was chosen to understand how TADs might enhance the treatment effects of the MEAW technique. MEAW and MEAW-TADs patients were consecutively identified, regardless of treatment outcome, in an attempt to minimize selection bias. Approval for the study was obtained from the University of Washington Institutional Review Board (IRB) under STUDY00013288.

Inclusion Criteria:

- AOB prior to treatment defined as a lack of vertical overlap of one or more incisors with teeth in opposing arch. The remaining incisors must not have contact with the opposing incisors as determined by the lateral cephalogram and/or intra-oral photographs
- At least 18 years of age at the start of treatment
- Pre- and post-treatment lateral cephalograms available. Reconstructed cephalograms from cone-beam computed tomography (CBCT) acceptable
- Completed orthodontic treatment with fixed appliances

Exclusion Criteria:

- Adults with craniofacial pathologies or syndromes, including cleft lip and/or palate
- Patients with significant mental, physical, or medical conditions that may have impacted compliance or tooth movement
- Orthognathic surgery
- The use of aligners
- The use of fixed or removable functional appliances

All patient records were deidentified prior to submission to investigators.

Data Collection

For all cases submitted, a data collection form was submitted along with deidentified records in order to gather the following:

1. age, race/ethnicity, and sex
2. treatment and retention times
3. significant medical and dental history
4. facial profile
5. molar classification right and left
6. maxillary and mandibular arch length discrepancies
7. crossbites
8. vertical facial pattern (high, normal, or low angle)
9. habits and habit appliances
10. extractions completed as part of treatment
11. TAD quantity and location of placement as part of treatment, if applicable
12. history of prior orthodontic treatment

Additionally, deidentified records were submitted to include: T1 and T2 lateral cephalometric images and intraoral frontal photographs in maximum intercuspation. When available, T3 lateral cephalograms and/or intraoral frontal photographs in maximum intercuspation were gathered to assess stability. Participating practitioners were compensated $30 for each case submitted.

Landmark Identification and POSI Scoring

Landmarks on lateral cephalograms were identified using Dolphin Imaging software (version 11.95; Dolphin Imaging and Management Solutions, Chatsworth, California) and measurements were generated using an automated, custom analysis. The assessors could not be blinded to the groups or time as the cephalograms contained identifying information, like specific rulers or the presence of an overbite. However, limiting the assessors' role only to landmark identification helped reduce investigator bias. Embedded millimetric rulers were used to correct for magnification in the Dolphin Imaging software. The longest clearly identifiable points on the same side of the ruler were marked in the software. When a millimetric ruler was not present in the cephalograms from one or both timepoints, these methods were utilized to correct for magnification:

1. If a ruler was present at another timepoint, it was used to calibrate that cephalogram, and then the corrected millimetric measurement for sella-nasion (SN) was recorded. This measurement was used to correct for magnification in the other timepoint missing a ruler for the same subject.
2. If no rulers were present at any timepoint for one subject, average values for SN of an 18-year-old of the same gender were used to correct for magnification on both lateral cephalograms.[23]

Landmark identification was performed on the cephalograms as submitted from participating clinicians with no changes to contrast, saturation, or brightness. The images were taken and landmarks were identified with the subject in natural head position with no rotational leveling of images. For bilateral structures that did not coincide, both right and left landmarks were identified, a ruler was placed on a straight line between the two landmarks, and the midpoint was selected to represent the landmark. All landmarks were identified initially by one examiner (AS) and reviewed independently by a second examiner (NA) (Figure 2). Any disagreements were resolved by consensus. If consensus could not be reached, a third examiner (GH) was consulted.

Reliability of this method of landmark identification was assessed for the two examiners. Ten lateral cephalometric radiographs, chosen at random in a representative ratio to the number of cases in each group, were re-landmarked 2 months after the initial landmarking. Cephalometric measurements in the custom analysis for this study from the first and second round of landmarking were compared to calculate the reliability of this method.

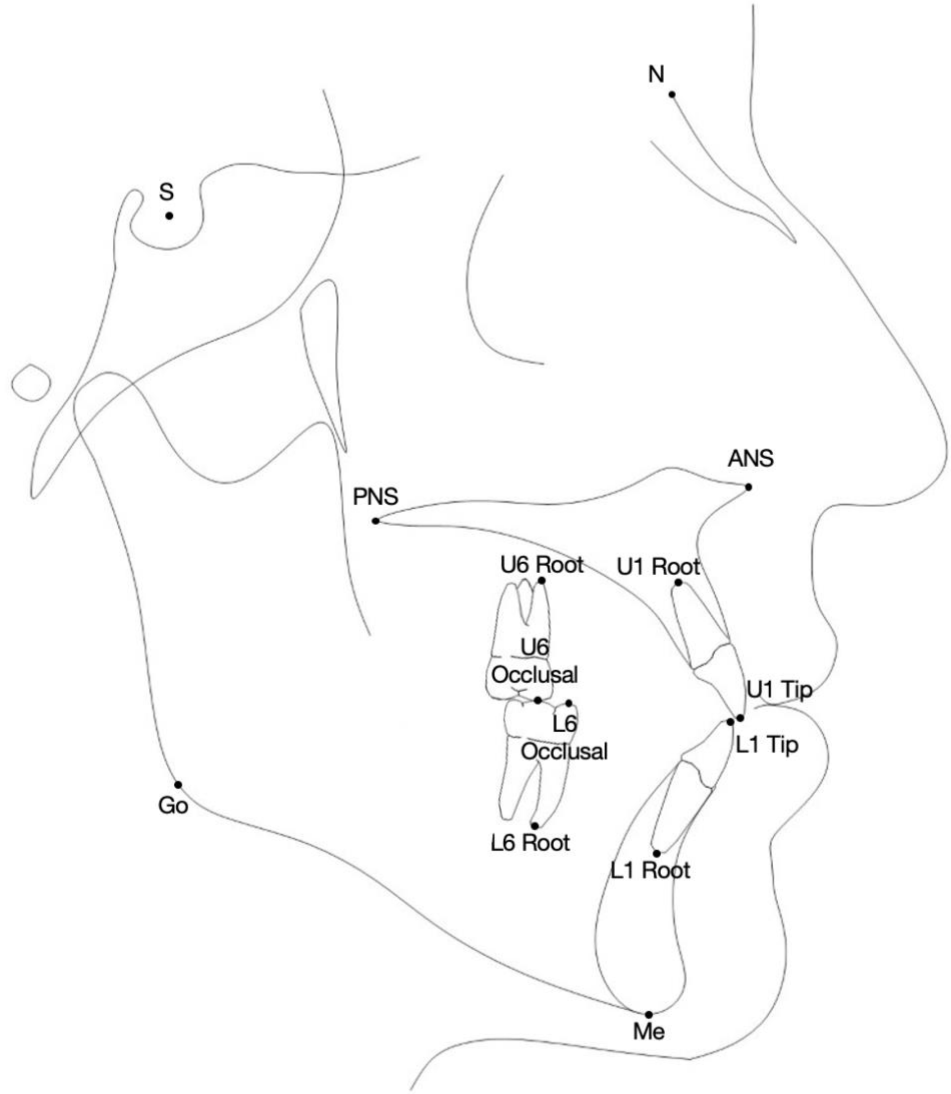

Figure 2. Summary of cephalometric landmarks identified on pre- and post-treatment lateral cephalograms: sella (S), nasion (N), anterior nasal spine (ANS), posterior nasal spine (PNS), menton (Me), gonion (Go), incisal edge of the maxillary incisor (U1 Tip), root apex of the maxillary incisor (U1 Root), incisal edge of the mandibular incisor (L1 Tip), root apex of the mandibular incisor (L1 Root), mesial cusp tip of the maxillary first molar (U6 Occlusal), mesial root apex of the maxillary first molar (U6 Root), mesial cusp tip of the mandibular first molar (L6 Occlusal), mesial root apex of the mandibular first molar (L6 Root).

Since long-term (T3) lateral cephalometric radiographs were not available for the vast majority of subjects, T3 intraoral photographs were used to assess stability. The photographs were scored in a blinded manner by two examiners (AS, GH) using the Photographic Openbite Severity Index (POSI) (Figure 3).[22,24] Where scores differed, a consensus score was obtained through discussion. The seven categories listed below were developed based on the number and type of teeth with vertical overlap:

0 = All four incisor with positive vertical overlap

1 = One or two maxillary lateral incisors without vertical overlap (but both maxillary central incisors have vertical overlap)

2 = One maxillary central incisor without vertical overlap (the other maxillary central has vertical overlap)

3 = Two maxillary central incisors without vertical overlap (at least one maxillary lateral has vertical overlap)

4 = All four maxillary incisors without vertical overlap

5 = All anterior teeth, including canines, without vertical overlap

6 = All anterior teeth, including canines, plus at least one first premolar without vertical overlap

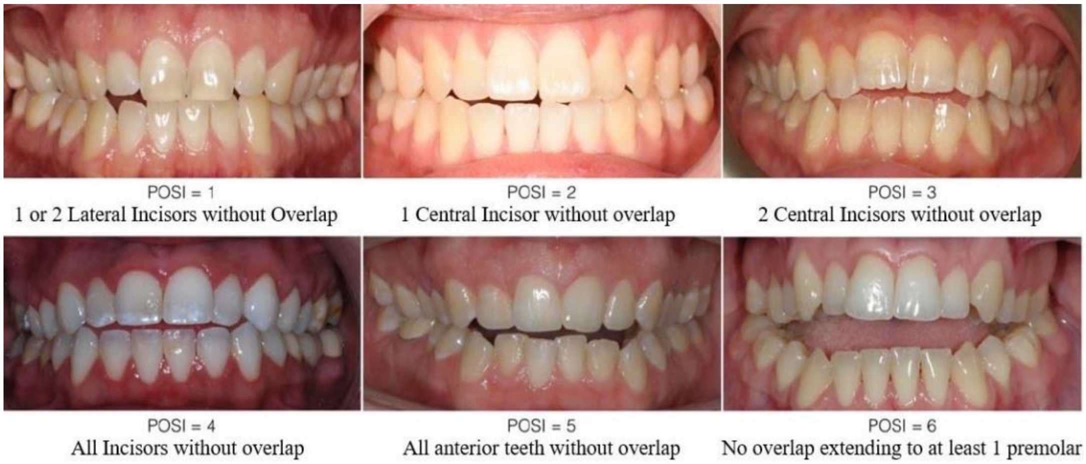

Figure 3. Photographic Openbite Severity Index (POSI) which uses intraoral frontal photographs in maximum intercuspation to rate openbite on a scale from 0 to 6.

Data Analysis

Sample Size Calculation

It was estimated that we could collect records for 40 patients in the MEAW group, 40 in the FA group, and 20 in the MEAW-TADs group. Based on these sample sizes and using a two-sided paired t-test with a 0.05 significance level, the power was 80% to demonstrate a change in cephalometric measures equal to 1/2 of a standard deviation (SD) or larger for the MEAW and FA groups. For the MEAW and MEAW-TADs groups, using the same assumptions, 80% power was associated with a change equal to 3/4 of a SD or larger. For comparison, YH Kim et al. reported changes for MEAW treatment of >2/3 SD for overbite (4.01 mm) and U6 long axis-SN (4.7 degrees), and greater than >1/2 SD for L6 long axis-MP (4.5 degrees).[15] Therefore, we felt that our target numbers were reasonable to investigate clinically significant differences.

Outcome Measures

1. Overbite (OB): measure of the distance from the U1 incisal edge to L1 incisal edge, perpendicular to the occlusal plane
2. Incisor dentoalveolar height
   - U1-PP: shortest distance from U1 incisor tip to a line through ANS and PNS, which are the two points constituting the palatal plane (PP)
   - L1-MP: shortest distance from L1 incisor tip to a line through gonion and menton, which are the two points constituting the mandibular plane (MP)
3. Incisor angulation
   - U1-PP: angular relation of a line on the U1 long axis (U1 incisor tip and U1 root apex) and a line through ANS and PNS
   - L1-MP: angular relation of a line on the L1 long axis (L1 incisor tip and L1 root apex) and a line through gonion and menton
4. Molar dentoalveolar height
   - U6-PP: shortest distance from U6 mesiobuccal cusp tip to a line through ANS and PNS
   - L6-mandibular plane (MP): shortest distance from L6 mesiobuccal cusp tip to a line through gonion and menton
5. Molar angulation
   - U6-SN: angular relation of a line on the U6 long axis (U6 mesial cusp tip to U6 mesial root apex) and a line through sella and nasion
   - L6-MP: angular relation of a line on the L6 long axis (L6 mesial cusp tip to L6 mesial root apex) and a line through gonion and menton

6. Mandibular plane angle (MPA): angular relation of a line through gonion and menton and a line through sella and nasion
7. Anterior facial height (AFH): distance from nasion to menton
8. Occlusal plane-SN: a line connecting the point bisecting the upper and lower first molar cusp tips and the point bisecting the incisal overbite

Figures 4 and 5 illustrate the landmarks identified on lateral cephalograms and measurements calculated.

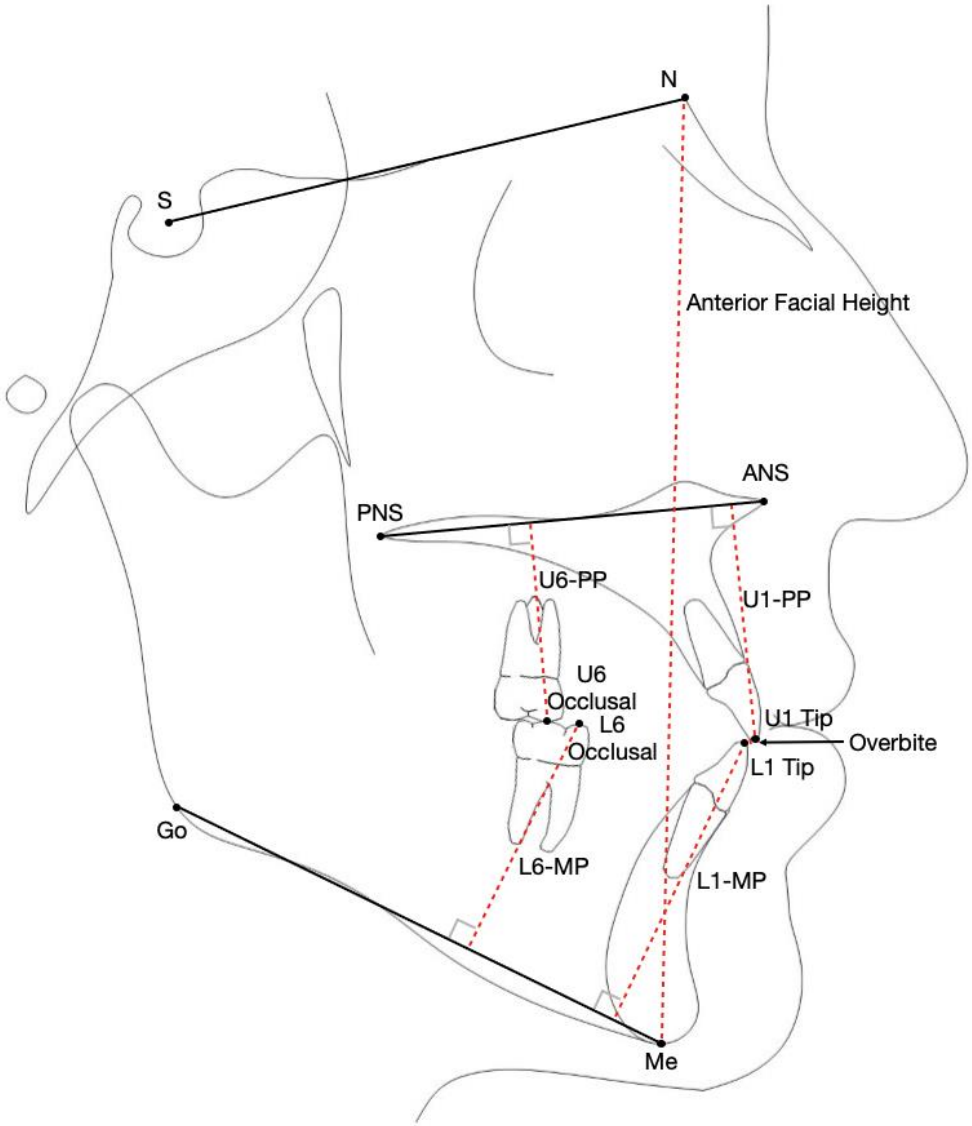

Figure 4. Linear measurements made using the landmarks identified on lateral cephalograms.

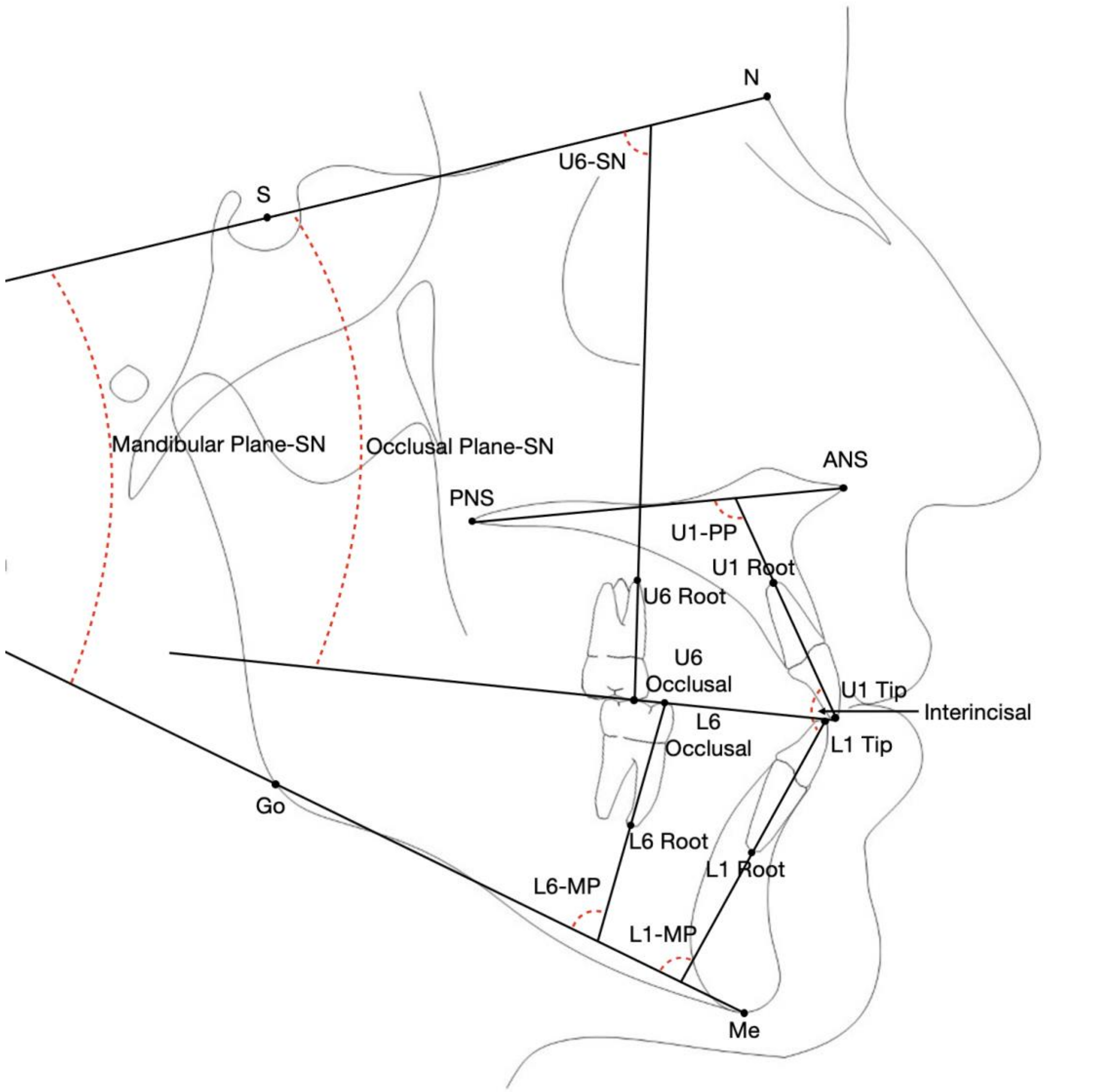

Figure 5. Angular measurements made using the landmarks identified on lateral cephalograms.

Treatment Modality

Treatment type was obtained from the data collection forms the providers completed for each subject submitted. For the control subjects, demographic and treatment data were also obtained. Missing teeth and extraction patterns were confirmed using clinical photographs and lateral cephalograms.

Treatment groups were as follows:

1. MEAW
2. FA (matched controls)
3. MEAW-TADs (also referred to as "TADs" group for simplicity)

Inherently, MEAW treatment begins with FA and then, when appropriate, progresses into multiloop edgewise archwires. This is typically done after rotations are resolved and teeth are aligned within their arches.[14] Thus both groups that utilized MEAW did also include a period of conventional full fixed appliance use prior to changing to multiloop edgewise archwires. History of prior orthodontic treatment was reported. Missing teeth were recorded along with any extractions as a part of treatment. Third molars were removed during treatment in many subjects, but these were not classified as extraction patients when matching controls. Time in treatment was calculated by the difference between the T1 records and the T2 records. Follow-up time was calculated as the time from T2 to T3.

Patient Characteristics

Patient characteristics were reported for all subjects gathered for this study. The demographics gathered included age, sex, and race/ethnicity. Diagnostic descriptors were also collected for subjects. These included facial profile, molar classification, arch length discrepancies (crowding and spacing), posterior crossbites, and habits. Vertical facial patterns were grouped by their mandibular plane (MP) to SN angular measurement into high angle (>39º), normal angle (27-39º), and low angle (<27º).

Statistical Analysis

Patient characteristics were compared using paired t-test and Welch's two-sample t-test for quantitative variables and McNemar's test, chi-squared test and Fisher's exact test for categorical variables.

Consensus Landmark Identification Reliability

To assess reliability, the means and standard deviations (SD) were computed for each set of cephalometric measurements, and then the differences were assessed using the intraclass correlation coefficient (ICC)[25] and Dahlberg's error[26]. An ICC > 0.75 generally indicates excellent agreement (i.e., the variation due to the different measurements is relatively small compared to the variation between subjects), 0.40 to 0.75 is fair to good agreement, and below 0.40 is poor agreement.

Dahlberg's error is an absolute measure of error and gives the average error of measurements in units of the variable being measured[26].

Treatment Success

Treatment success was defined as positive overbite on the T2 lateral cephalogram.

Treatment Effects

To evaluate the effect of treatment, cephalometric measures were summarized by the mean and standard deviation for the three groups at pre-treatment (T1) and post-treatment (T2), and for the change between pre- and post-treatment (T2-T1).

Group averages were compared at T1 and T2, as well as the average change from T1 to T2 and change within each group. In addition, T2 values and T2-T1 changes were compared adjusting for T1 values. Because adjustment resulted in minimal changes to the p-values, we have reported unadjusted p-values. However, the adjusted values are also reported in situations where the interpretation of the crude and adjusted p-values was different.

Linear regression was used for all comparisons and implemented using generalized estimating equations (GEE) with an exchangeable working correlation structure and robust standard errors to account for the matching between MEAW and FA groups and allow for heteroscedasticity. To complement the statistical testing, 95% confidence intervals were reported for all treatment changes and comparisons. A two-sided significance level of 0.05 was used for all statistical tests. Comparisons were based on all available data. No adjustments were made to the p-values to account for the multiple testing.

Stability

The comparison of POSI scores was restricted to subjects with intraoral center photographs at all three time points. Stability was considered acceptable if the POSI score was either 0 or 1. Fisher's exact test was used to compare POSI scores at T1 and T3 between the 3 groups, and logistic regression used to compare POSI scores at T3 adjusting for follow-up time.

All statistical analyses were done using R statistical software, Version 4.2.0. R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

RESULTS

RELIABILITY

The reliability for all outcome measures calculated from landmark identification by consensus were excellent, except the reliability of the angular measurement of L6-MP was in the good to excellent range. The angular measurement of U6-SN reliability was lower than most of the other measures as well (Appendix 1).[25]

SAMPLE

A total of 33 patients were initially collected for the MEAW sample. A matched comparison group of 33 subjects treated with FA was also assembled. Finally, records from 15 subjects were collected who were treated with MEAW and TADs in the maxilla and MEAW in the mandible. We did not quite meet our target sample sizes of 40, 40, and 20, respectively.

The mean age at T1 of the MEAW sample was 29.5 years, FA was 32.4 years, and MEAW-TADs was 25.6 years. 73% of the MEAW and the FA groups were female while 87% of those treated with MEAW-TADs were female. The FA group was the most ethnically diverse, while the MEAW sample contained no Asians and the MEAW-TADs sample was 100% Asian. Demographic data are summarized in Table I.

Characteristic	MEAW n = 33[1]	FA n = 33[1]	TADs n = 15[1]	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
Age (years)						
Mean (SD)	29.5 (11.0)	32.4 (10.8)	25.6 (7.3)	0.37[1]	0.15[2]	0.015[2]
Range	17.3, 66.2	19.4, 61.5	18.2, 44.5			
Sex				1.0[3]	0.29[4]	0.29[4]
Female	24 (72.7%)	24 (72.7%)	13 (86.7%)			
Race/ethnicity				0.12[5]	<.001[5]	<.001[5]
White/Caucasian	23 (69.7%)	18 (54.5%)	0 (0.0%)			
Asian	0 (0.0%)	4 (12.1%)	15 (100.0%)			
Hispanic/Latino	9 (27.3%)	7 (21.2%)	0 (0.0%)			
Black/African American	0 (0.0%)	2 (6.1%)	0 (0.0%)			
Multiracial or Biracial	1 (3.0%)	2 (6.1%)	0 (0.0%)			

[1]Paired t-test
[2]Welch's two-sample t-test
[3]McNemar's test
[4]Chi-squared test
[5]Fisher's exact test

Table I. Age, sex, and race/ethnicity of patients.

Dentofacial Characteristics

The MEAW group had considerably more patients with Class III molars and concave facial profiles than the other two groups. All three groups had mild crowding in the upper and lower arches. Posterior crossbites were present in about 40% of the subjects. While tongue posture and/or thrust was reported in none of the MEAW subjects, it was present in about 50% of the subjects in the FA and 100% of the MEAW-TADs groups (Table II).

Characteristic	MEAW n = 33[1]	FA n = 33[1]	TADs n = 15[1]	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
Profile				0.009	0.006	0.020
Concave	7 (21.2%)	0 (0.0%)	0 (0.0%)			
Convex	9 (27.3%)	17 (51.5%)	13 (86.7%)			
Straight	17 (51.5%)	16 (48.5%)	2 (13.3%)			
Molar classification				0.026	0.003	0.11
I	13 (39.4%)	15 (45.5%)	4 (26.7%)			
II	4 (12.1%)	10 (30.3%)	10 (66.7%)			
III	16 (48.5%)	6 (18.1%)	1 (6.6%)			
Significant asymmetry	0 (0.0%)	2 (6.1%)	0 (0.0%)			
Arch length discrepancy (Maxillary)				0.28[1]	0.13[2]	0.002[2]
Mean (SD)	2.2 (2.5)	2.8 (1.4)	1.4 (1.3)			
Range	-2.0, 7.0	1.0, 5.0	-0.5, 4.0			
Arch length discrepancy (Mandibular)				0.95[1]	0.003[2]	<.001[2]
Mean (SD)	2.9 (2.4)	2.9 (1.2)	0.9 (1.9)			
Range	-4.0, 7.0	1.0, 5.0	-2.6, 4.8			
Posterior crossbite				0.62	0.65	0.83
None	18 (54.5%)	19 (57.6%)	10 (66.7%)			
Bilateral	8 (24.2%)	5 (15.2%)	2 (13.3%)			
Unilateral	7 (21.2%)	9 (27.3%)	3 (20.0%)			
Vertical facial pattern				1.0	0.54	0.54
High Angle	17 (51.5%)	17 (51.5%)	10 (66.7%)			
Low Angle	1 (3.0%)	1 (3.0%)	0 (0.0%)			
Normal	15 (45.5%)	15 (45.5%)	5 (33.3%)			
Habits				<.001	<.001	0.030
None	32	11	0			
Digit	0	3	0			
Tongue posture and/or thrust	0	19	15			
Mouth breathing	1	0	0			
Extractions				0.10	0.38	0.013
None with current treatment	18 (54.5%)	25 (75.8%)	5 (33.3%)			
Two or more third molars	14 (42.4%)	6 (18.1%)	9 (60.0%)*			
Two or more premolars	1 (3.0%)	2 (6.1%)**	1 (6.7%)			
Prior orthodontic treatment				0.13	0.14	0.75
Yes	13 (41.9%)	8 (24.0%)	3 (20.0%)			
No	18 (50.1%)	25 (76.0%)	12 (80.0%)			
Unknown	2	0	0			

The p-values are based on the chi-square test, unless noted otherwise. Negative (-) arch length discrepancy indicates spacing.
*Two patients had U7s/L8s extracted. One patient had only UR8 extracted.
**One patient had U4s/LR4/LL6 extracted.
[1]Paired t-test
[2]Welch’s two-sample t-test

Table II. Descriptors of patient population.

Treatment Modality

Thirteen of fifteen subjects in the MEAW-TADs group had a single posterior, paramedian palatal TAD while one had three palatal TADs and the last subject had bilateral buccal TADs. The majority of subjects in the MEAW and FA groups were treated non-extraction while the majority of those treated with MEAW-TADs had two or more third molars extracted. Additionally, roughly 40% of the MEAW and approximately 20% of the FA and MEAW-TADs groups had prior orthodontic treatment (Table II).

Treatment Duration

The mean treatment duration was 25.6 months for the MEAW group, 23.2 months for the FA group, and 25.5 months for the MEAW-TADs group (Table III).

Characteristic	MEAW n = 33	FA n = 33	TADs n = 15	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
Treatment time (T1 to T2) (months)						
Mean (SD)	25.6 (9.6)	23.2 (8.3)	25.5 (8.1)	0.28[1]	0.97[2]	0.30[2]
Range	9, 50	10, 52	15, 46			
Months of Follow-up (T2 to T3)						
Mean (SD)	37.2 (37.7)	11.9 (4.7)	58.2 (27.2)	0.014[2]	0.092[2]	<.001[2]
Range	5, 166	6, 24	12, 98			
Not available	16	21	3			

[1]Paired t-test
[2]Welch's two-sample t-test

Table III. Treatment duration.

Treatment Effects

Treatment success, as defined by positive overbite on the T2 lateral cephalogram, was achieved in 100% of MEAW, 97% of FA, and 93% of the MEAW-TADs sample. The FA group was matched to the MEAW group in part by initial overbite severity, and their mean millimetric overbite as measured on the lateral cephalograms were -2.6 mm and -2.2 mm, respectively. Alternatively, the MEAW-TADs group's mean overbite (OB) at T1 was -5.4 mm. The T2 overbites were not statistically significantly (P >0.05) different between groups: 1.3 mm for MEAW, 1.3 mm for FA, and 1.6 mm for MEAW-TADs. The change in overbite in the MEAW-TADs subjects was nearly double what was observed in MEAW alone (p-value = <.001). However, if adjusting for T1 overbite, there was not a significant difference (p-value = 0.10) in change in overbite between the MEAW and MEAW-TADs groups. Data on overbites can be found in (Table IV).

Characteristic	MEAW n = 33	FA n = 33	TADs n = 15	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
T1						
Mean (SD)	-2.6 (2.0)	-2.2 (1.8)	-5.4 (2.0)	0.48	<.001	<.001
Range	-7.6, 0.3	-6.6, 1.0	-7.9, -0.7			
T2						
Mean (SD)	1.3 (0.7)	1.3 (1.0)	1.6 (0.7)	0.76	0.34	0.26
Range	0.0, 3.0	-1.4, 3.7	-0.1, 2.3			
Change T2-T1						
Mean (SD)	3.8 (1.9)	3.5 (2.0)	7.0 (1.9)	0.60	<.001	<.001
Range	1.2, 8.5	0.6, 8.7	2.7, 9.6			
p-value	<.001	<.001	<.001			

Table IV. Overbite in millimeters at T1 and T2.

Five subjects had at least one timepoint for which at least one missing or poor-quality landmark could not be accurately identified. All other landmarks were identified in these subjects and the measurements included in comparisons.

The significant skeletal and dentoalveolar findings, on average, in subjects treated with MEAW were as follows (Table V, Figure 6):

- no changes in mandibular plane angulation relative to SN nor any changes in anterior facial height
- extrusion of incisors
    - U1-PP: 1.8 mm (SD = 1.9 mm)
    - L1-MP: 2.4 mm (SD = 1.7 mm)
- retraction of incisors
    - U1-PP: 4.4º (SD = 8.6º)
    - L1-MP: 5.6º (SD = 6.3º)
- extrusion of the lower first molar: 0.6 mm (SD = 1.3 mm)
- distal tipping of first molars
    - U6-SN: 3.5º (SD = 6.7º)
    - L6-MP: 8.1º (SD = 5.9º)

Figure 6 illustrates changes seen with MEAW treatment in a subject from the study most closely matching the average changes seen in all subjects in this group.

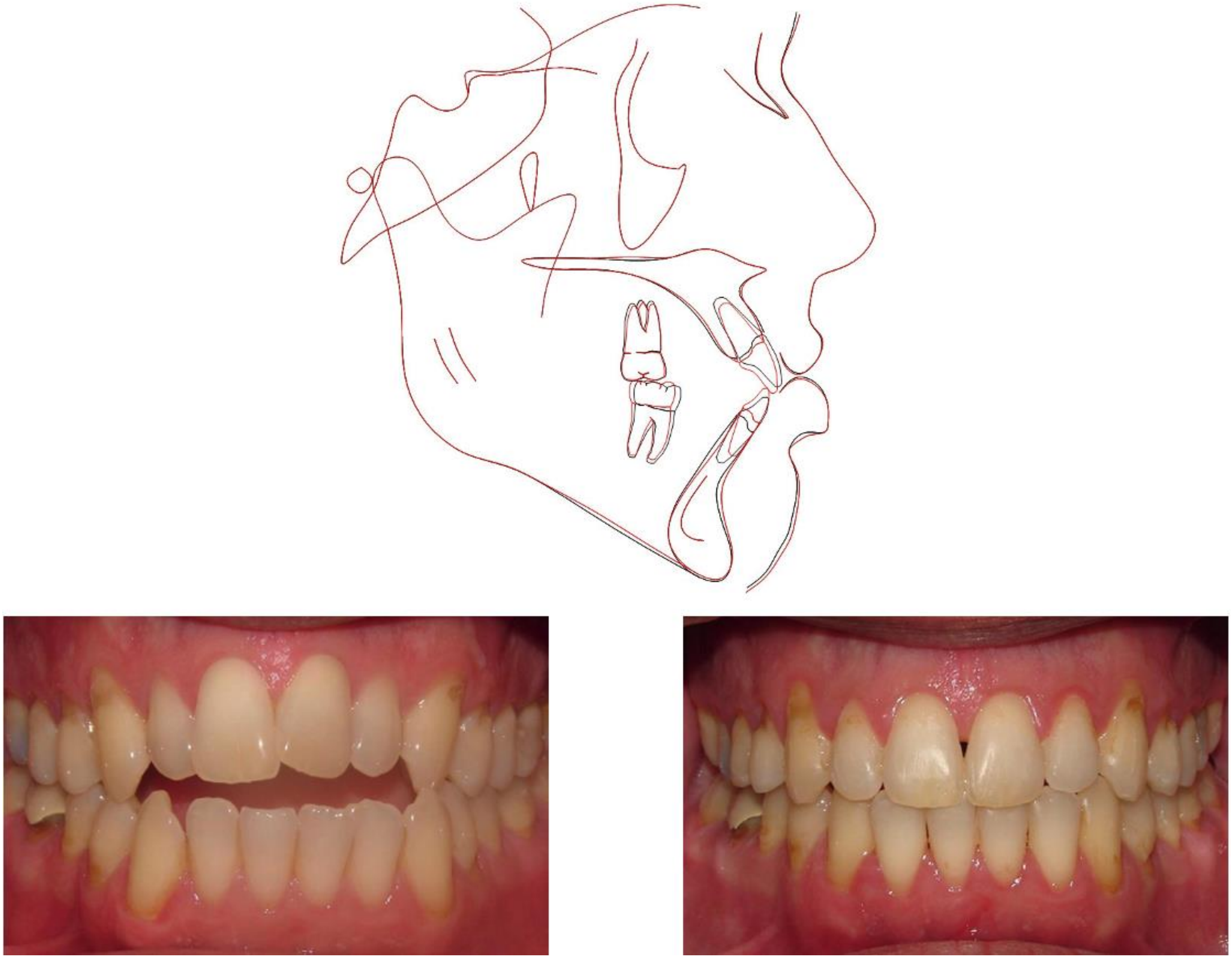

Figure 6. An example AOB case treated with MEAW with dental and skeletal changes closely resembling the changes seen on average in all MEAW cases. This male patient was 34 years and 9 months at the start of his 16-month treatment. In the superimposition, black is T1 and red is T2. Upper and lower incisor extrusion and retraction was noted along with lower first molar extrusion. Upper and lower first molar crowns tipped distally and no significant skeletal changes were noted. On the bottom, the left photograph is at T1 and the right is at T2.

The significant skeletal and dentoalveolar findings, on average, in subjects treated with FA were as follows (Table V, Figure 7):

- no changes in mandibular plane angulation relative to SN nor any changes in anterior facial height

- extrusion of incisors
    - U1-PP: 2.4 mm (SD = 2.6 mm)
    - L1-MP: 1.4 mm (SD = 1.2 mm)
- retraction of upper incisors: 5.4º (SD = 10.3º)
- extrusion of the lower first molar: 0.6 mm (SD = 1.1 mm)
- distal tipping of lower first molars: 4.7º (SD = 4.7º)
- clockwise rotation of the occlusal plane: 1.7º (SD = 2.3º)

Figure 7 illustrates changes seen with FA treatment in a subject from the study most closely matching the average changes seen in all subjects in this group.

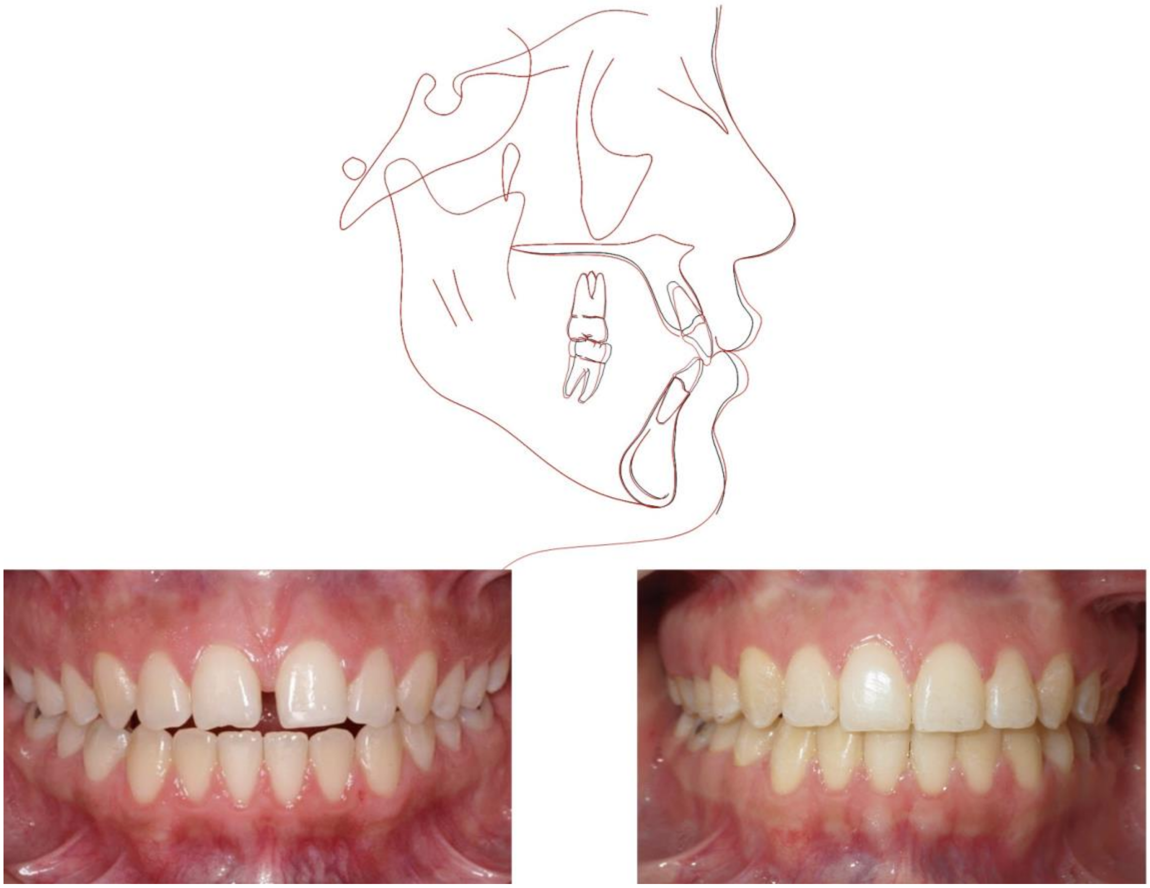

Figure 7. An example AOB case treated with FA with dental and skeletal changes closely resembling the changes seen on average in all FA cases. This female patient was 21 years and 4 months at the start of her 21-month treatment. In the superimposition, black is T1 and red is T2. Upper and lower incisor extrusion and upper incisor retraction were noted, as was mild lower first molar extrusion. Lower first molar crowns tipped distally and no significant skeletal changes were noted. The occlusal plane rotated clockwise. On the bottom, the left photograph is at T1 and the right is at T2.

The significant skeletal and dentoalveolar findings, on average, in subjects treated with MEAW-TADs were as follows (Table V, Figure 8):

- no changes in mandibular plane angulation relative to SN
- decreased anterior facial height: 1.2 mm (SD = 1.3 mm)
- extrusion of incisors
    - U1-PP: 1.6 mm (SD = 1.0 mm)

- L1-MP: 2.5 mm (SD = 1.7 mm)
- retraction of incisors
  - U1-PP: 11.1º (SD = 5.2º)
  - L1-MP: 7.2º (SD = 4.7º)
- intrusion of the upper first molar: 1.3 mm (SD = 1.4 mm)
- distal tipping of first molars
  - U6-SN: 4.5º (SD = 5.2º)
  - L6-MP: 4.6º (SD = 5.3º)
- clockwise rotation of the occlusal plane: 1.4º (SD = 2.0º)

Figure 8 illustrates changes seen with FA treatment in a subject from the study most closely matching the average changes seen in all subjects in this group.

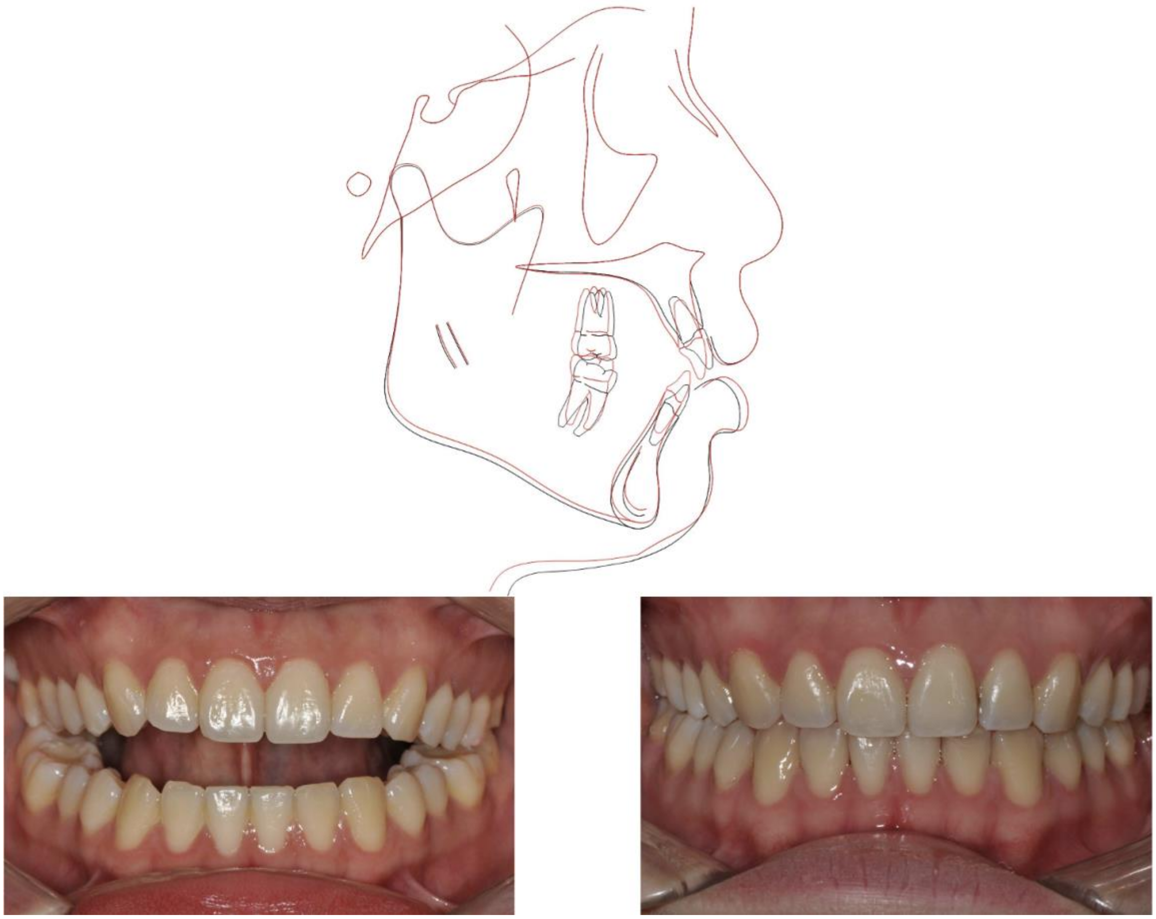

Figure 8. An example AOB case treated with MEAW with TADs with dental and skeletal changes closely resembling the changes seen on average in all MEAW-TADs cases. This female patient was 20 years and 1 month at the start of her 22-month treatment. In the superimposition, black is T1 and red is T2. Upper and lower incisor extrusion and retraction were noted. Upper first molars intruded and anterior facial height decreased. Upper and lower first molar crowns tipped distally. In this subject, the lower first molar extruded, but on average, subjects in this group did not have significant lower first molar extrusion. The occlusal plane rotated clockwise. On the bottom, the left photograph is at T1 and the right is at T2.

Maxillary anterior dentoalveolar height assessed by U1-PP was not significantly different between any of the groups. In the mandible, the mean amount of lower incisor extrusion was greatest in the MEAW and MEAW-TADs groups at 2.4 mm and 2.5 respectively (Table V).

Posterior dentoalveolar heights were also examined as U6-PP and L6-MP. The MEAW-TADs group saw the only significant change in molar vertical position (U6-PP) with mean intrusion of 1.3 mm. The difference in change of molar height between the MEAW-TADs versus the MEAW group was significant with a p-value < 0.001. Mandibular posterior dentoalveolar height (L6-MP) had no significant differences between groups (Table V).

One change seen in openbite treatment is in the occlusal plane. The bisected occlusal plane was measured as a line from the midpoint between U6/L6 mesiobuccal cusp tips to the midpoint between U1/L1 incisal edges relative to a line from sella to nasion (occ plane-SN). The MEAW subjects had a mean change of 0.0º (p-value = 0.95), the FA group saw a mean change in occlusal plane of 1.7º (p-value < 0.001), while the TADs group had a change of 1.4º (p-value = 0.006). The increased occlusal plane signified an overall clockwise rotation of the occlusal plane relative to SN. The change was significant only for FA versus MEAW (p-value = 0.03) (Table V).

The upper incisor relative to the palatal plane (U1-PP) retroclined significantly more in the subjects treated with TAD mechanics. The lower incisor angulation decreased on averagein all groups, however. The decrease in both the MEAW (5.6º) and the TADs (7.2º) were not significantly different than each other (p-value = 0.31), but both were significantly (MEAW vs FA p-value = 0.012, TADs vs FA p-value = 0.001) more than the subjects treated with FA (Table V).

It was also discovered that, on average, the U6-SN angle decreased, or the maxillary first molar crowns tipped back, significantly in both the MEAW (3.5º) and MEAW-TADs (4.5º) groups.The change was not significantly different in the MEAW group compared to the MEAW-TADs group (p-value = 0.56) (Table V).

The average lower first molar angulation differed in that the FA and TADs groups were most similar (p-value = 0.98) with a tip back of these molars of 4.7º and 4.6º, respectively. MEAW saw the greatest distal tipping of L6-MP of 8.1º. This was significantly greater than the change seen in both FA and MEAW-TADs groups. Table V contains data on molar angulation.

A key skeletal measure assessed was mandibular plane angle (MPA) as the angular relation of MP-SN. The FA subjects were chosen based in part on initial MPA to match the T1 MPAs of the MEAW group. Therefore, there was no significant difference between their initial measurements. No significant changes occurred in MPA within each group nor when comparing the three groups.

The other skeletal change evaluated in our study was anterior facial height as measured linearly from nasion to menton. During treatment, the only significant change in AFH was the MEAW-TADs group with a decrease of 1.2 mm on average. This change was significant when compared to the MEAW group (p-value = <0.001) with or without adjustment for T1. These values can be found in Table V.

Characteristic	MEAW n = 33	FA n = 33	TADs n = 15	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
Dentoalveolar height (mm)						
U1-PP						
Mean (SD)	1.8 (1.9)	2.4 (2.6)	1.6 (1.0)	0.25	0.59	0.098
p-value	<.001	<.001	<.001			
L1-MP						
Mean (SD)	2.4 (1.7)	1.4 (1.2)	2.5 (1.7)	0.004	0.95	0.022
p-value	<.001	<.001	<.001			
U6-PP						
Mean (SD)	0.5 (1.3)	-0.1 (1.3)	-1.3 (1.4)	0.11	<.001	0.002
p-value	0.058	0.77	<.001			
L6-MP						
Mean (SD)	0.6 (1.3)	0.6 (1.1)	0.3 (0.8)	0.94	0.32	0.23
p-value	0.014	0.002	0.15			
Dentoalveolar angular (deg)						
Occ Plane-SN						
Mean (SD)	0.0 (3.7)	1.7 (2.3)	1.4 (2.0)	0.03	0.09	0.68
p-value	0.95	<.001	0.006			
U1-PP						
Mean (SD)	-4.4 (8.6)	-5.0 (10.3)	-11.1 (5.2)	0.79	0.001	0.005
p-value	0.003	0.004	<.001			
L1-MP						
Mean (SD)	-5.6 (6.3)	-1.9 (5.9)	-7.2 (4.7)	0.012	0.31	0.001
p-value	<.001	0.062	<.001			
U6-SN						
Mean (SD)	-3.5 (6.7)	0.0 (5.6)	-4.5 (5.2)	0.026	0.56	0.005
p-value	0.005	0.98	<.001			
L6-MP						
Mean (SD)	-8.1 (5.9)	-4.7 (4.7)	-4.6 (5.3)	0.009	0.039	0.98
p-value	<.001	<.001	<.001			
Skeletal						
MP-SN (deg)						
Mean (SD)	0.0 (1.4)	0.0 (1.3)	-0.2 (1.7)	0.92	0.70	0.65
p-value	0.86	0.97	0.59			
AFH (mm)						
Mean (SD)	0.6 (2.0)	0.4 (2.1)	-1.2 (1.3)	0.82	<.001	0.001
p-value	0.11	0.21	<.001			

Table V. Skeletal and dentoalveolar changes between T2 - T1.

Stability

Treatment stability was only assessed in patients who had successful treatment and had long-term photographs. Patients missing intraoral photos at any timepoint, (T1, T2, or T3) were omitted from assessment of stability using POSI. T1-T3 intraoral photographs were available for 18 of 33 MEAW, 12 of 33 FA, and 11 of 15 MEAW-TADs subjects.

100% of subjects with T1-T3 photos in all three treatment groups completed treatment with a POSI score of 0. Stability, as defined by POSI scores of 0 or 1 at T3, was confirmed in 100% of MEAW, 92% of FA, and 82% of MEAW-TADs subjects. The mean follow-up times were 37.2 months (SD = 37.7 months) for MEAW, 11.9 months (SD = 4.7 months) for FA, and 58.2 months (SD = 27.2 months) for MEAW-TADs. Given the longer average follow-up time in the MEAW-TADs group, stability was assessed adjusted for follow-up time. Given adjustment for follow-up time, Fisher's exact test demonstrated MEAW was not statistically significantly more stable than the other two treatment groups (MEAW vs FA p-value = 0.40; MEAW vs MEAW-TADs p-value = 0.14). Prevalence of POSI scores at all 3 timepoints can be found in Table VI.

Characteristic	MEAW n = 18[1]	FA n = 12[1]	TADs n = 11[1]
POSI at T1			
1	1 (5.6%)	1 (8.3%)	0 (0%)
2	2 (11%)	1 (8.3%)	0 (0%)
3	1 (5.6%)	0 (0%)	1 (9.1%)
4	6 (33%)	8 (67%)	1 (9.1%)
5	3 (17%)	1 (8.3%)	2 (18%)
6	5 (28%)	1 (8.3%)	7 (64%)
POSI at T2			
0	18 (100%)	12 (100%)	11 (100%)
POSI at T3			
0	14 (78%)	3 (25%)	8 (73%)
1	4 (22%)	8 (67%)	1 (9.1%)
4	0 (0%)	1 (8.3%)	1 (9.1%)
6	0 (0%)	0 (0%)	1 (9.1%)

[1]n (%)

Table VI. POSI scores of subjects with intraoral photographs at T1-T3.

DISCUSSION

This study aimed to compare the correction of AOB using the MEAW technique versus subjects treated with conventional full fixed appliances and versus a third group treated with the MEAW technique and the addition of TADs for skeletal anchorage. Success, as defined by positive overbite on the T2 lateral cephalogram, was similar in all groups, ranging from 93-100% of subjects in each group. However, the picture of success is not fully defined by the percentage of subjects achieving positive overbite. The MEAW group started with 2.6 mm of openbite and the FA had 2.2 mm of openbite, but the TADs subjects presented with 5.4 mm of openbite. Thus, the subjects treated with TADs were much more severe initially. It could be argued that, due to severity, these subjects necessitated the TAD augmentation of MEAW for the best chance at openbite closure non-surgically. These subjects saw a mean overbite improvement of 7.0 mm, roughly 2x that seen in the FA or MEAW group.

The two largest studies on the effects of MEAW for AOB correction by Chang and Moon[17] and YH Kim et al.[15] reported a convergence of occlusal planes, lower molar distal tipping, and incisor extrusion and retroclination during treatment in non-growing patients. Chang and Moon differed from YH Kim et al. in that they also reported lower first molar intrusion on average and counter-clockwise rotation of the mandible in ten of sixteen non-growing patients. YH Kim et al. differed in that they reported upper molar intrusion and distal tipping of the upper molars in addition to the lower molars with MEAW treatment.[15] Neither study reported significant skeletal changes as measured by anterior facial height or mandibular plane angle.

In this study, neither MEAW or FA demonstrated a change in MPA or AFH. FA had similar effects to MEAW for incisor extrusion and retraction, lower first molar extrusion, and lower first molar crowns tipping distally. In comparison to MEAW, FA had no distal tipping of upper first molars and less lower incisor retraction. Very minor, but significant ($P < .05$), clockwise rotation of the occlusal plane was seen on average with FA treatment but not MEAW therapy. Thus, the differences between MEAW and FA were minor. Neither caused the molar intrusion or AFH and MPA decreases that would be beneficial to AOB correction. These changes have been described previously as benefits of MEAW over FA, but were not shown in our subjects.

MEAW predates the use of TADs in orthodontics as the MEAW technique has been utilized since 1967. The use of skeletal anchorage through bone plates was first described in 1985 by Jenner.[27] T-W Kim and H Kim, Proffit, and Janson and Valarelli,[11–13] among many others, have since proposed and shown that TADs may allow for treatment of more challenging cases that may have previously necessitated orthognathic surgical correction. This is accomplished through absolute anchorage and the ability to intrude molars, allowing for mandibular autorotation and AOB correction with controlled incisor extrusion. It would only make sense to attempt to combine the optimal effects of MEAW with TADs for ideal correction of AOB. Some researchers have utilized these techniques together, but no large-sample studies exist regarding MEAW with TADs.

Freitas et al. published a case report of a 24-year-old man with an openbite from second premolar to second premolar treated with MEAW and mandibular TADs without any extractions.[28] The paper described treatment success in closing the openbite through intrusion of molars with absolute anchorage of the TADs followed by MEAW to "finalize and refine the [openbite] closure and the tooth uprighting" with extrusion of the incisors as well. The authors also reported counter-clockwise mandibular rotation. The treatment was very successful in closing the AOB and proved stable for 50 months of follow-up. While the superimposition included displayed significant mandibular molar intrusion, there was an equal and opposite extrusion of the molars in the maxillary arch that lacked TADs. This maxillary molar extrusion countered the mandibular molar intrusion and the reported counter-clockwise mandibular rotation was not demonstrated in the superimposition.

Our study determined that the addition of maxillary TADs with MEAW therapy had all of the same treatment effects as MEAW alone. The addition of TADs also added upper first molar intrusion and decreased anterior facial height. Lower first molars did not significantly extrude in the MEAW-TADs sample. The mandibular plane angle would be expected to decrease with molar intrusion and decreased anterior facial height, but the average amount of mandibular plane closure we observed was minimal (0.2 mm).

The molars are often mesioangular in patients with openbite propping open the mandible by a wedge effect.[29] Thus, intrusion or tipping back of the posterior dentition is a desired effect that has been suggested as a benefit of MEAW technique.[14,15,17] MEAW and MEAW used in conjunction with TADs did have an overall distal tipping effect on upper first molars that was not seen in FA treatment. As for the lower molars, MEAW caused distal tipping of 8.1º. The amount of distal tipping was more similar in the FA and MEAW-TAD subjects, with distal tipping of 4.7º and 4.6º, respectively. MEAW demonstrated significantly more L6 distal tip than both the FA and MEAW-TADs groups. Interestingly, the significantly greater distal crown tipping of lower molars in MEAW subjects over MEAW-TADs subjects could not be explained by a difference in treatment modality as both groups had received traditional MEAW therapy in the mandibular arch,

Due to the position of the molars and the wedge effect, it could be expected that the mandibular plane angle (MPA), as measured from MP-SN, would be affected when molars change vertical position during treatment. However, the mean MPA change was not significant in any group. This could be explained by the molar angulation since the mesial cusp tips could extrude on the lower first molars, as was seen in the MEAW sample, but these teeth could also tip distally and not cause significant mandibular rotation. The mandibular plane angle would be expected to decrease in the MEAW-TADs group as an effect of upper first molar intrusion and decreased anterior facial height, but the mean change in MPA was too small to reach statistical significance.

MEAW has also been described as having better individual tooth control, important in minimizing excess incisor extrusion that could negatively impact smile esthetics. However, the difference in the amount of upper incisor extrusion between MEAW and FA as well as MEAW and MEAW-TADs groups was not statistically significant. Mandibular incisor extrusion was observed in all treatment groups and was not significantly different between MEAW (2.4 mm) and MEAW-TADs (2.5 mm) groups. The findings are the same since MEAW subjects had the same mechanics in the lower arch as the MEAW-TADs group, due to all TADs being placed in the maxilla. The lower incisor extrusion in the MEAW sample was significantly greater than that seen in the FA treatment group (1.4 mm). The significantly greater lower incisor extrusion in both groups using MEAW could be attributed to the decreased load deflection rate due to the boot loops distal to the lateral incisors in MEAW therapy. This may allow more lower incisor extrusion when wearing anterior vertical elastics compared to FA treatment. One negative side effect noted in some patients with extreme incisor extrusion was the development of periodontal defects, such as black triangles and recession (Figure 9).

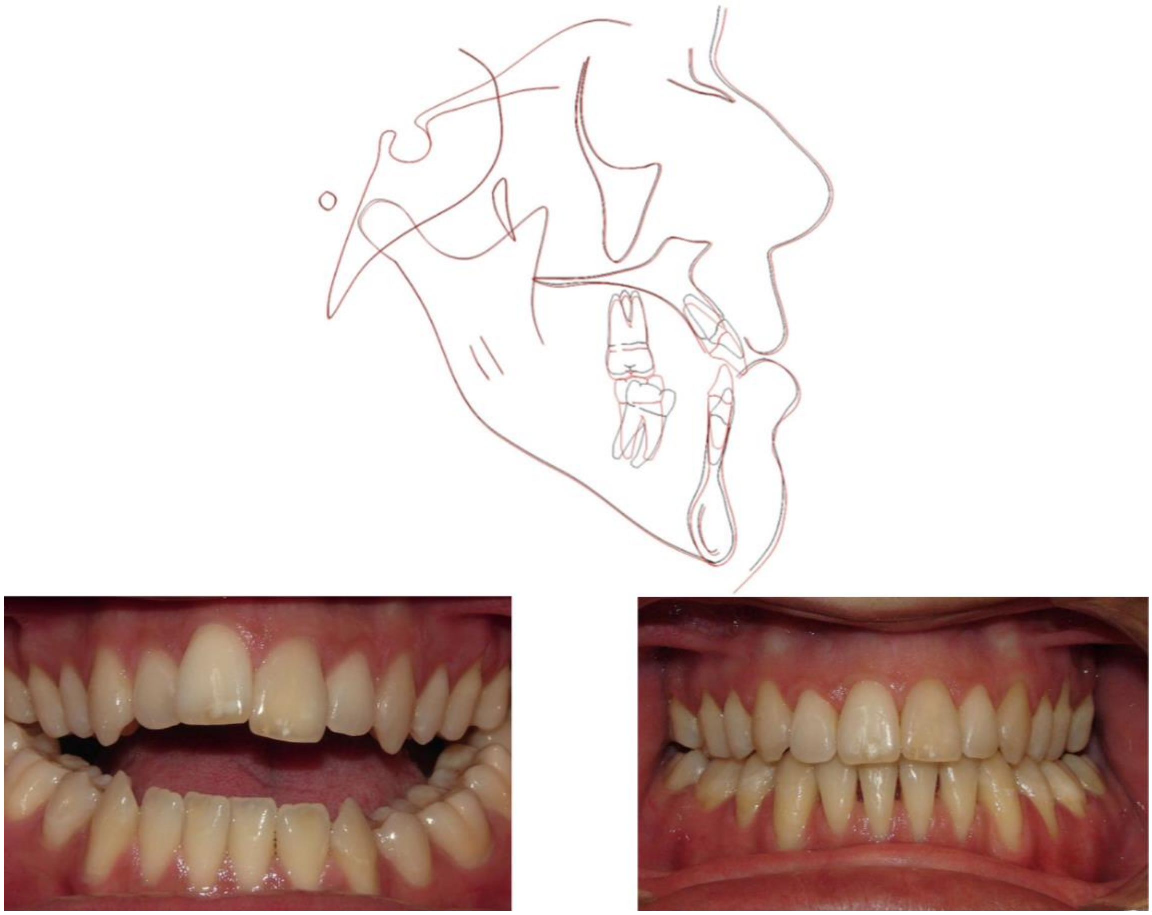

Figure 9. A male patient who was 18 years and 10 months before treatmentwith MEAW (bottom left). The superimposition (top) shows the T1 structures in black and T2 structures in red. He had 4.8 mm of upper and 5.1 mm of lower incisor extrusion during treatment. Negative periodontal sequelae, including black triangles and recession, are noted after treatment (bottom right).

Increased interincisal angles measure anterior openbite closure by incisor retraction or uprighting, named the "drawbridge effect,"[8,11] which was a described effect of MEAW by previous researchers.[15,17] Looking at the changes of maxillary and mandibular incisors more clearly identifies treatment effects than simply assessing interincisal angle. The upper incisor relative to the palatal plane (U1-PP) uprighted significantly more on average in the subjects treated with TADs, which could also provide anchorage for this movement.

Change in occlusal plane was another outcome assessed as there was no consensus in the literature regarding the direction of rotation with MEAW therapy. No change in occlusal plane was seen in the MEAW group, however, significant, but minor, average clockwise rotations were seen in the FA sample of 1.7º and in the MEAW-TADs subjects of 1.4º. In both MEAW and FA groups, upper molars did not show significant vertical movement. Lower first molars and upper incisors extruded the same amount, on average, in both groups. Therefore, the only difference in dental changes between the groups lied in the lower incisor extrusion with significantly more seen in the MEAW subjects. Occlusal plane clockwise rotation was noted in the FA, but not the MEAW, group. Thus, the increased lower incisor extrusion in MEAW subjects countered any clockwise occlusal plane rotation. The clockwise rotation seen in the MEAW-TADs group is believed to be due to maxillary molar intrusion and incisor extrusion. When compared to MEAW, only the change seen in FA subjects met the threshold for statistical significance ($P < .05$). The amount observed in the MEAW-TADs group was not significantly greater than that seen in the MEAW sample ($P > .05$).

Stability as defined as POSI of 0 or 1 at T3 was present in 100% of MEAW, 92% of FA, and 82% of MEAW-TADs subjects with T1 through T3 intraoral frontal photographs. However, no conclusions can be drawn from this study about differences in stability between treatment modalities due to the limited number of subjects with T3 records available. 55% of MEAW, 36% of FA, and 73% of MEAW-TADs subjects had T1-T3 intraoral photographs available.

LIMITATIONS

The samples and data included in this investigation were gathered from single providers for the MEAW and MEAW-TADs groups. While encouraged to submit all relevant cases, successful and not, selection bias may still have occurred. While skill levels and techniques add an additional variable that cannot be controlled for when comparing treatment outcomes, both MEAW and MEAW-TADs providers were proficient in their respective techniques, and essentially all patients in the three groups had successful treatment.

The control group of conventional fixed appliances was treated by multiple providers. Thus, this group might be expected to have good generalizability. Variability inherent to lateral cephalograms as the primary source of data in this study cannot always be controlled for. This variability may include magnification error, head position, and landmark identification. It is worth noting that in landmark identification by consensus, and resulting automated measurements from these landmarks, all measures had excellent reliability with the exception of upper and lower molar angulation. U6-SN angle was calculated to be on the low end of excellent reliability as an outlier in that group (ICC = 0.79) and L6-MP angle had good reliability (ICC = 0.73). Photographs were used to assess stability with the POSI rating that may be affected by the angle of the camera to the patient. These challenges were accounted for and attempted to be minimized by landmark identification and POSI scoring by consensus with overall excellent reliability.

Additionally, when comparing findings between groups, as well as to the population in general, it must be remembered that the MEAW data comes from patients treated in Florida of varying racial backgrounds while the MEAW-TADs group is from a provider in Korea treating an entirely Asian population. While the scope of this study is not intended to include retention options and their success, there is no denying that the retention type, recommended wear regimens, and compliance could have an impact on stability of results. This should be examined in future studies on the stability of the MEAW technique.

CONCLUSIONS

The following conclusions can be made from this study:

1. Treatment success rates were high in all three treatment groups.
2. Incisors exhibited a pattern of extrusion and retroclination in all groups.
3. The dental and skeletal effects seen in the MEAW and FA groups were similar, except MEAW patients exhibited greater distal crown tipping of the first molars and more lower incisor extrusion. Molar vertical positions were minimally changed in the MEAW and FA groups.

4. Only the MEAW-TADs group demonstrated significant maxillary molar intrusion and reduction of AFH. This group also had significantly more upper incisor retraction than the MEAW group.

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APPENDIX

Measure	1st Mean (SD)	2nd Mean (SD)	Diff. (SD) [95% CI]	ICC (95% CI)	D. Error (Min, Max)
MP-SN (degree)	41.3	41.5	-0.2 (0.7)	1.00	0.5
	(7.4)	(7.3)	[-0.7, 0.3]	(0.99, 1.00)	(0.0, 1.2)
AFH (mm)	120.7	120.9	-0.2 (0.5)	1.00	0.4
	(8.3)	(8.5)	[-0.6, 0.2]	(1.00, 1.00)	(0.0, 0.9)
OB (mm)	-1.1	-1.1	0.0 (0.2)	1.00	0.2
	(2.9)	(3.0)	[-0.2, 0.1]	(0.99, 1.00)	(0.0, 0.4)
U6-PP (mm)	24.3	24.6	-0.2 (0.3)	0.99	0.3
	(3.6)	(3.5)	[-0.5, 0.0]	(0.99, 1.00)	(0.0, 0.9)
L6-MP (mm)	31.9	32.1	-0.2 (0.5)	0.97	0.4
	(2.4)	(2.3)	[-0.6, 0.2]	(0.94, 0.99)	(0.0, 1.2)
U1-PP (mm)	30.4	30.6	-0.2 (0.4)	0.99	0.3
	(4.0)	(3.7)	[-0.5, 0.1]	(0.98, 1.00)	(0.0, 0.9)
L1-MP (mm)	39.7	39.8	-0.1 (0.4)	0.98	0.3
	(2.2)	(2.1)	[-0.4, 0.2]	(0.96, 0.99)	(0.0, 0.8)
U6-SN (degree)	73.8	76.2	-2.5 (3.5)	0.79	2.9
	(7.2)	(5.5)	[-4.9, 0.0]	(0.60, 0.89)	(0.2, 9.7)
L6-MP (degree)	83.7	83.1	0.6 (2.4)	0.73	1.7
	(2.9)	(3.8)	[-1.1, 2.4]	(0.51, 0.86)	(0.4, 5.5)
U1-PP (degree)	110.4	110.7	-0.3 (2.2)	0.96	1.5
	(7.9)	(7.3)	[-1.8, 1.3]	(0.92, 0.98)	(0.2, 3.9)
L1-MP (degree)	92.0	91.1	0.9 (2.3)	0.96	1.7
	(9.6)	(8.4)	[-0.8, 2.5]	(0.93, 0.98)	(0.0, 6.3)
Occ Plane - SN	20.8	21.0	-0.2 (0.7)	0.99	0.5
(degree)	(5.8)	(5.8)	[-0.7, 0.2]	(0.98, 1.00)	(0.0, 1.2)

D. Error = Dahlberg's Error

Appendix 1. Reliability of lateral cephalogram measurements from landmark identification by consensus.

Characteristic	MEAW n = 33	FA n = 33	TADs n = 15	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
T1						
Mean (SD)	40.2 (6.4)	38.8 (6.2)	44.7 (6.0)	0.36	0.016	0.001
Range	27.6, 50.6	26.6, 53.6	37.5, 54.4			
T2						
Mean (SD)	40.4 (7.0)	38.8 (5.6)	44.4 (6.0)	0.30	0.039	0.001
Range	25.7, 54.5	27.1, 52.1	36.4, 54.6			
Unknown	3	0	0			
Change T2-T1						
Mean (SD)	0.0 (1.4)	0.0 (1.3)	-0.2 (1.7)	0.92	0.70	0.65
Range	-2.4, 3.9	-2.3, 2.9	-3.2, 3.8			
Unknown	3	0	0			
p-value	0.86	0.97	0.59			

Appendix 2. Mandibular plane angle (MP-SN) in degrees.

Characteristic	MEAW n = 33	FA n = 33	TADs n = 15	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
T1						
Mean (SD)	122.1 (7.9)	119.7 (8.9)	125.0 (6.6)	0.24	0.18	0.019
Range	103.9, 140.4	104.7, 137.5	112.0, 137.5			
T2						
Mean (SD)	122.5 (8.6)	120.1 (7.9)	123.7 (6.5)	0.25	0.59	0.088
Range	105.6, 140.9	104.1, 135.0	112.9, 137.5			
Unknown	3	0	0			
Change T2-T1						
Mean (SD)	0.6 (2.0)	0.4 (2.1)	-1.2 (1.3)	0.82	<.001	0.001
Range	-3.4, 5.2	-2.6, 7.5	-3.3, 0.9			
Unknown	3	0	0			
p-value	0.11	0.21	<.001			

Appendix 3. Anterior facial height as a linear measurement in millimeters from nasion to menton.

Characteristic	MEAW n = 33	FA n = 33	TADs n = 15	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
T1						
Mean (SD)	29.1 (3.1)	28.5 (4.6)	30.3 (1.5)	0.50	0.060	0.033
Range	21.3, 34.7	16.6, 35.7	26.7, 32.3			
T2						
Mean (SD)	30.9 (3.8)	30.9 (3.9)	31.9 (1.6)	0.99	0.19	0.20
Range	23.0, 39.5	23.0, 38.6	27.8, 34.3			
Change T2-T1						
Mean (SD)	1.8 (1.9)	2.4 (2.6)	1.6 (1.0)	0.25	0.59	0.098
Range	-3.2, 5.2	-1.5, 13.7	-0.7, 3.2			
p-value	<.001	<.001	<.001			

Appendix 4. Maxillary anterior dentoalveolar height as a millimetric linear measurement from the incisal edge of the central incisor to the palatal plane (U1-PP).

Characteristic	MEAW n = 33	FA n = 33	TADs n = 15	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
T1						
Mean (SD)	39.5 (2.9)	40.8 (4.0)	40.5 (2.9)	0.11	0.27	0.71
Range	35.1, 47.2	31.6, 48.9	36.9, 47.0			
T2						
Mean (SD)	41.9 (2.8)	42.2 (3.7)	42.9 (4.1)	0.68	0.36	0.56
Range	37.0, 47.4	35.8, 49.4	37.9, 53.2			
Change T2-T1						
Mean (SD)	2.4 (1.7)	1.4 (1.2)	2.5 (1.7)	0.004	0.95	0.022
Range	-1.7, 5.6	-0.5, 4.4	-0.5, 6.2			
p-value	<.001	<.001	<.001			

Appendix 5. Mandibular anterior dentoalveolar height as a millimetric linear measurement from the incisal edge of the central incisor to the mandibular plane (L1-PP).

Characteristic	MEAW n = 33	FA n = 33	TADs n = 15	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
T1						
Mean (SD)	24.5 (2.4)	25.1 (3.2)	25.1 (2.1)	0.41	0.35	0.96
Range	20.1, 29.5	19.9, 34.1	21.8, 28.4			
Unknown	1	1	0			
T2						
Mean (SD)	24.8 (2.6)	25.1 (2.8)	23.8 (2.4)	0.67	0.18	0.097
Range	19.8, 29.8	19.5, 31.5	19.5, 27.9			
Unknown	1	0	0			
Change T2-T1						
Mean (SD)	0.5 (1.3)	-0.1 (1.3)	-1.3 (1.4)	0.11	<.001	0.002
Range	-2.0, 5.0	-2.6, 3.4	-2.8, 1.9			
Unknown	2	1	0			
p-value	0.058	0.77	<.001			

Appendix 6. Posterior dentoalveolar height of U6-PP in millimeters (mm).

Characteristic	MEAW n = 33	FA n = 33	TADs n = 15	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
T1						
Mean (SD)	31.0 (2.5)	31.6 (3.2)	34.4 (3.3)	0.40	<.001	0.006
Range	25.0, 36.1	22.6, 36.9	30.1, 40.7			
Unknown	1	1	0			
T2						
Mean (SD)	31.6 (2.5)	32.3 (2.9)	34.6 (3.6)	0.31	0.002	0.022
Range	25.9, 36.3	25.7, 37.8	30.6, 41.6			
Unknown	1	0	0			
Change T2-T1						
Mean (SD)	0.6 (1.3)	0.6 (1.1)	0.3 (0.8)	0.94	0.32	0.23
Range	-1.9, 4.7	-1.6, 3.1	-1.0, 1.7			
Unknown	2	1	0			
p-value	0.014	0.002	0.15			

Appendix 7. Posterior dentoalveolar height of L6-MP (mm).

Characteristic	MEAW, N = 33	FA, N = 33	MEAW vs FA p-value	TADs, N = 15	MEAW vs TADs p-value	FA vs TADs p-value
T1						
Mean (SD)	17.3 (4.5)	15.4 (5.2)	0.13	24.0 (5.1)	<.001	<.001
Range	4.2, 25.8	4.0, 25.4		17.2, 35.0		
Unknown	1	1		0		
T2						
Mean (SD)	17.3 (6.2)	17.1 (5.0)	0.89	25.4 (5.2)	<.001	<.001
Range	-0.7, 30.5	8.4, 29.7		18.8, 35.1		
Unknown	4	0		0		
Change T2-T1						
Mean (SD)	0.0 (3.7)	1.7 (2.3)	0.030	1.4 (2.0)	0.090	0.68
Range	-9.8, 9.3	-3.0, 8.4		-1.5, 5.5		
Unknown	5	1		0		
p-value	0.95	<.001		0.006		

Appendix 8. Angular relation of bisected occlusal plane relative to SN.

Characteristic	MEAW n = 33	FA n = 33	TADs n = 15	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
T1						
Mean (SD)	114.7 (7.2)	115.4 (10.1)	113.3 (6.5)	0.74	0.50	0.38
Range	95.3, 127.4	98.6, 142.6	101.7, 129.0			
T2						
Mean (SD)	110.3 (9.9)	110.4 (9.1)	102.2 (4.7)	0.97	<.001	<.001
Range	89.1, 132.4	93.3, 127.5	94.1, 110.2			
Change T2-T1						
Mean (SD)	-4.4 (8.6)	-5.0 (10.3)	-11.1 (5.2)	0.79	0.001	0.005
Range	-26.2, 12.8	-40.1, 10.0	-20.0, -2.8			
p-value	0.003	0.004	<.001			

Appendix 9. Angular relation of upper central incisor to palatal plane (U1-PP).

Characteristic	MEAW n = 33	FA n = 33	TADs n = 15	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
T1						
Mean (SD)	90.6 (9.0)	93.9 (7.8)	95.8 (6.7)	0.11	0.024	0.38
Range	72.6, 109.2	79.8, 109.7	86.7, 109.7			
T2						
Mean (SD)	85.0 (11.2)	92.0 (7.7)	88.6 (3.9)	0.003	0.098	0.037
Range	64.7, 110.3	77.0, 107.2	82.9, 95.6			
Change T2-T1						
Mean (SD)	-5.6 (6.3)	-1.9 (5.9)	-7.2 (4.7)	0.012	0.31	0.001
Range	-20.8, 6.9	-12.3, 13.2	-18.8, 0.1			
p-value	<.001	0.062	<.001			

Appendix 10. Angular relation of lower central incisor to mandibular plane (L1-MP).

Characteristic	MEAW n = 33	FA n = 33	TADs n = 15	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
T1						
Mean (SD)	78.5 (7.2)	79.2 (6.4)	76.1 (6.4)	0.67	0.25	0.11
Range	68.0, 94.7	66.9, 90.9	65.0, 91.9			
Unknown	1	1	0			
T2						
Mean (SD)	74.8 (7.3)	79.0 (6.3)	71.6 (6.4)	0.013	0.13	<.001
Range	63.5, 97.1	67.6, 92.5	58.8, 84.0			
Unknown	4	0	0			
Change T2-T1						
Mean (SD)	-3.5 (6.7)	0.0 (5.6)	-4.5 (5.2)	0.026	0.56	0.005
Range	-16.6, 8.7	-11.5, 12.6	-18.3, 1.5			
Unknown	5	1	0			
p-value	0.005	0.98	<.001			

Appendix 11. Angular relation of upper first molar to sella-nasion (U6-SN).

Characteristic	MEAW n = 33	FA n = 33	TADs n = 15	MEAW vs FA p-value	MEAW vs TADs p-value	FA vs TADs p-value
T1						
Mean (SD)	81.8 (8.0)	82.2 (6.9)	82.2 (4.7)	0.82	0.81	0.99
Range	62.2, 98.1	68.9, 104.1	71.3, 88.8			
Unknown	1	1	0			
T2						
Mean (SD)	73.9 (6.1)	77.7 (7.2)	77.6 (6.1)	0.020	0.050	0.95
Range	59.4, 86.1	63.7, 98.0	66.4, 86.1			
Unknown	1	0	0			
Change T2-T1						
Mean (SD)	-8.1 (5.9)	-4.7 (4.7)	-4.6 (5.3)	0.009	0.039	0.98
Range	-24.5, 2.1	-20.6, 2.1	-16.2, 4.3			
Unknown	2	1	0			
p-value	<.001	<.001	<.001			

Appendix 12. Angular relation of lower first molar to mandibular plane (L6-MP).