Orthodontic Treatment of Anterior Open-bite With and Without Skeletal Anchorage

Jason C. Johnson

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Committee:

Anne-Marie Bollen

Greg Huang

Sylvain Chamberland

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Abstract

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Jason C. Johnson

Chair of the Supervisory Committee:

Anne-Marie Bollen

Department of Orthodontics

Introduction: Although there appears to be mounting evidence that skeletal anchorage (TADs) may offer benefits in the treatment of anterior open bite (AOB), there remains a lack of studies comparing outcomes and stability in patients treated with and without skeletal anchorage in growing versus non-growing individuals. The purpose of this study is to compare outcomes of AOB treatment with fixed appliances only (non-TADs) to treatment with fixed appliances in conjunction with TADs. Effects of growth and open-bite severity on treatment success and stability are explored.

Methods: Pre- (T1) and post-treatment (T2) lateral cephalograms were compared for 68 TAD and 42 non-TAD AOB patients using a custom analysis. T1 and T2 intraoral photographs were also scored using the Photographic Open-bite Severity Index (POSI). One-year retention (T3) photographs were measured for 58 of these patients, also using the POSI scale. Multiple linear and logistic regression models were utilized to explore effects of growth, pre-treatment severity, and location of TAD placement on treatment success and stability.

Results: Treatment success rates were similar between TAD (83.8%) and non-TAD (88.1%) AOB patients. Growth during treatment did not demonstrate a significant influence on treatment success (defined by overbite > 0). Growing and non-growing patients treated with TADs tended to show greater changes in cephalometric measurements than their non-TAD counterparts, particularly in change in lower face height, anterior face height, and maxillary molar vertical height. Patients with TADs in both arches tended to exhibit even more noticeable skeletal and facial changes, with reduced extrusion of incisors. Stability rates were higher for TAD patients (80.0%) compared to non-TAD patients (57.1%), and higher for non-growers (83.3%) compared to growers (50.0%), though these findings were not statistically significant.

Conclusion: The success rates for patients treated orthodontically for anterior open bite in this study were high. This study suggests that beneficial vertical changes can be obtained with the use of skeletal anchorage for molar intrusion in open bite patients, particularly when it is utilized in both upper and lower arches. Open bite patients with growth potential may also benefit from the use of TADs during treatment, as it appears to limit the vertical growth pattern normally expected. Practitioners should be aware of the relapse potential in open bite patients, especially in growing patients.

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INTRODUCTION

Anterior open bite (AOB) is defined by a lack of vertical overlap between the incisal edges of maxillary and mandibular anterior teeth. Patients with this malocclusion often experience functional consequences such as difficulty in speech, in swallowing, and incising food due to altered position of the tongue against the anterior teeth and hard palate.[1] Psychologic effects have also been noted, as patients have reported dissatisfaction with the appearance of their anterior teeth.[2] A variety of factors contribute to the etiology of this malocclusion, such as unfavorable growth patterns, a high mandibular plane angle (MPA), and oral habits such as anomalous tongue posture and digit sucking.[3] Due to its complex and multifactorial etiology, AOB remains one of the most challenging malocclusions for orthodontists to successfully treat and retain.

Patients with AOB can be treated using a variety of orthodontic treatment approaches. Some cases of AOB are treated with edge-wise fixed appliances. In this approach, vertical elastics are used in the anterior aspect of the dentition, and correction of open bite is due in large part to extrusion of the incisors.[4]

In certain cases of AOB of skeletal origin, many practitioners will elect to treat these patients with orthognathic surgery, which allows intrusion of the posterior segments. This is particularly relevant when extrusion of the incisors is contraindicated due to pre-existing excess gingival display. Though positive results are often achievable with surgery, orthodontic treatment combined with orthognathic surgery can be prone to vertical relapse, and the expense and risks associated with surgery are challenging for many patients to accept.[5] Additionally, surgical treatment is generally not performed until late adolescence or adulthood, when facial growth has subsided.

The utilization of temporary anchorage devices (TADs) has become an increasingly popular technique for correcting AOB as a less invasive alternative to orthognathic surgery.[6] Mini-plates or mini-screws are used to provide skeletal anchorage for vertical traction of maxillary and/or mandibular posterior teeth. Reports have shown that molar intrusion with TADs can induce auto-rotation of the mandible in a counter-clockwise direction, thereby limiting the amount of incisor extrusion required to achieve positive overbite.[7,8] Accompanying improvements in vertical soft tissue measurements including reduced lower facial height and improved lip competency have also been demonstrated.[9,10]

The effects of growth during treatment of AOB with TAD assisted molar intrusion is poorly understood. Mandibular growth during treatment of AOB has been hypothesized to be responsible for differences observed in treatment outcomes between patients categorized by age in one study.[7] The same report found both young and older patients to be subject to vertical relapse due to re-eruption of posterior teeth following active treatment. Other studies limited to adult patients have demonstrated that a majority of relapse of intruded maxillary molars occurred during the first year of retention.[11,12]

While both stand-alone comprehensive fixed appliance treatment and comprehensive fixed appliances in conjunction with TADs are routinely being used to treat patients with AOB, there is not yet a consensus on which of these methods is most successful in treating AOB and preserving the corrected vertical relationships.[13,14] Although there appears to be mounting evidence of benefits that TADs may offer in treatment of AOB, there remains a lack of studies comparing outcomes and stability in patients treated with and without skeletal anchorage in growing versus non-growing individuals.

The purpose of this retrospective, cohort study was to compare treatment outcomes of AOB treatment with comprehensive fixed appliances to treatment with fixed appliances in conjunction with TADs. This study explores the effect of growth and pre-treatment open-bite severity on treatment success and stability after at least one year of retention.

MATERIALS AND METHODS

This project was approved by the University of Washington IRB. The sample population in this retrospective study consisted of adolescent and adult patients who received one of two methods of orthodontic treatment to address their AOB:

1) Comprehensive fixed appliances *without* skeletal anchorage (Non-TAD group)
2) Comprehensive fixed appliances *with* skeletal anchorage (TAD group)

Patient Inclusion Criteria:

- Patient must have undergone comprehensive orthodontic treatment (limited/Phase 1 treatment not accepted)
- Patient must have a pre-treatment AOB that is defined by having no incisors in occlusal contact, and at least one incisor lacking vertical overlap with teeth in opposing arch. This is determined by examining the patient's initial cephalogram and intra-oral photographs.

- Presence of good quality, diagnostic pre-treatment and post-treatment lateral cephalometric radiographs.
- Where possible, intra-oral photographs at least one-year post-treatment to assess stability.

Exclusion Criteria

- Patients lacking good quality, diagnostic pre-treatment and post-treatment lateral cephalometric radiographs.
- Patients with non-diagnostic pre-intervention and end-of-treatment intraoral photographs.
- Patients with clefts, craniofacial syndromes, or other medical conditions that may affect ability to comply with orthodontic treatment
- Patients treated with orthognathic surgery to address the AOB.

Orthodontic practitioners were recruited by the primary investigator to identify previously treated AOB patients. Contributing practitioners were asked to share consecutively treated AOB cases to limit selection bias, though this was not always verifiable. Practitioners were also requested to contribute TAD and non-TAD patients; a majority of practitioners only contributed patients from one of the specified groups. The primary investigator furthermore identified all qualifying TAD and non-TAD AOB patients from the University of Washington Orthodontic clinic database who had treatment completed between the years 2014-2017. Participating practitioners were instructed to share de-identified pre-treatment (T1) and post-treatment (T2) lateral cephalograms, as well as de-identified pre-treatment (T1), post-treatment (T2), and if available, one-year retention (T3) intraoral photographs.

To ensure blinding of the primary investigator, all records, including pre-treatment (T1) and post-treatment (T2) lateral cephalometric radiographs and T1, T2, and T3 intraoral photographs were assigned a random study ID by the primary investigator's research assistant. The lateral cephalometric radiographs were then imported into Dolphin imaging software (version 11.0; Dolphin Imaging and Management Solutions, Chatsworth, CA). Cephalometric landmarks, summarized in Figure 1, were identified on each image by the primary investigator, and measurements were generated using a custom analysis. The primary investigator who did all measurements and scoring of photographs and lateral cephalograms was blinded to the type of treatment the patient had undergone.

A standard millimetric ruler in the cephalostat was used to calibrate the millimetric measurements. When a ruler was not present on the cephalometric image, an estimate of the mesio-distal width of the lower first molar was used for calibration (N=17). Consistent with average first molar mesio-distal width reported in previous publications, 11.5 mm was used as the calibration measurement.[15,16]

De-identified T1, T2, and T3 intraoral photographs were measured by the primary investigator. An index recently developed by a research team at the University of Washington Orthodontic department was used to score the relative open-bite severity at each time point, based on intraoral photographs.[17] The Photographic Open-bite Severity Index (POSI) has seven categories, defined by the type and number of teeth that do not have vertical overlap (Figure 2):

0 = All four incisors with positive overlap

1 = One or two maxillary lateral incisors without vertical overlap (but both 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 incisor has vertical overlap)

4 = All four maxillary incisors without vertical overlap

5 = All anterior teeth, including canines, without overlap

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

Patients identified from the University of Washington database who did not have one-year retention (T3) intraoral photographs were contacted by primary investigator and offered a complimentary retainer check/adjustment visit to present to the UW clinic for follow-up intraoral photographs. No other compensation was provided to any patient or practitioner for participation in the study.

Intra-rater reliability was calculated for the primary investigator; twenty randomly selected lateral cephalometric radiographs were re-traced, and 20 randomly selected intra-oral photographs were re-rated at least 1 month apart.

OUTCOME MEASURES

Treatment success

Success of treatment was identified based on the following outcome measures:

1) Positive overbite (>0 mm) on post-treatment (T2) lateral cephalograms.
2) Post-treatment (T2) POSI equal to zero, indicating positive overlap of all anterior teeth.

Cephalometric overbite measurements were based on the vertical position of the most anterior central incisor. Because patients with a positive cephalometric overbite may clinically lack vertical overlap of all anterior teeth, intraoral frontal photographs were used to verify severity of the open-bite.

Treatment stability

Where possible, retention (T3) intraoral photographs at least one-year post-treatment were obtained. No lateral cephalometric images were requested for the retention stage, so only POSI scoring on photographs was completed for T3. Stability of treatment was based on the same criteria used for post-treatment photographic evaluation:

1) Retention POSI equal to zero, indicating positive overlap of all anterior teeth.

Effects of Growth

To evaluate the effects of growth during orthodontic treatment on success and stability, TAD and Non-TAD groups were subdivided into four treatment categories:

1) Non-TAD patients (fixed appliances only) *with* growth during treatment

2) Non-TAD patients (fixed appliances only) *without* growth during treatment

3) TAD patients (and fixed appliances) *with* growth during treatment

4) TAD patients (and fixed appliances) *without* growth during treatment

Growth was defined by at least 2.5 mm change of mandibular length throughout the course of orthodontic treatment (Articulare – Gnathion), measured on the pre-treatment to post-treatment lateral cephalograms.

Skeletal anchorage location

Each patient in the TAD sample had mini-screws placed in at least one of the two arches to aid with molar intrusion during treatment. A large majority of these patients had TADs placed exclusively in the maxillary arch; a small number of these patients (N=11) had TADs placed in both maxillary and mandibular arches. To explore the effects of the use of TADs in one or both arches on treatment success and stability, a subsample of these 11 patients was created. Due to the small size of this sub-sample, growing (N=2) and non-growing (N= 9) patients were joined in the same grouping.

Pre-treatment Severity

To assess the effect of pre-treatment AOB severity on the success and stability of treatment, all patients were categorized into one of three tiers of AOB severity, based on cephalometric measurements of overbite:

1) Mild anterior open-bite (T1 overbite = 0 to -2 mm)

2) Moderate anterior open-bite (T1 overbite = -2.1 to -4 mm)

3) Severe anterior open-bite (T1 overbite = -4.1 mm or greater)

TAD and non-TAD patients were separately divided into one of these three tiers of severity so that use of skeletal anchorage could be compared between patients of similar pre-treatment characteristics.

Statistics and predictive models

Descriptive statistics were performed on the patient sample. Binary success of treatment was identified based on the following outcome measures:

2) Positive overbite (mm) on post-treatment lateral cephalogram.
3) Post-treatment POSI equal to zero, indicating positive overlap of all anterior teeth.

Multiple linear regression models were employed to examine the difference between treatment groups in mean change from baseline to post-treatment severity for each cephalometric variable. Additional models also examined the change from baseline POSI score to post-treatment. These models adjusted for baseline severity and possible confounders of tooth extraction, gender, age and clinic site. Models were also fit for the change from baseline POSI score to scores one year after treatment, but adjustment in these models was only made for baseline severity and tooth extraction due to clinical importance but otherwise lack of sample size. Inference was based on Wald tests that use robust estimates of the standard error.

Logistic regression models were developed to assess differences in odds of treatment success and stability by treatment group. Adjustment was made for tooth extraction, but other possible confounders were not included due to low event rate. Additional models were fit with interaction terms for either growth of at least 2.5mm or pre-treatment severity to assess if growth or pre-treatment severity modified the effect of treatment. Inference was based on likelihood ratio tests.

All statistical inference was guided by a two-sided 0.05 level of significance and two-sided 95% confidence intervals, but there was no correction for multiple comparisons, so care was taken to interpret findings as exploratory. Microsoft Excel was used for data management and R 3.6.1 (R Core Team) software was used for statistical analysis.

RESULTS

A total of 110 AOB patients were included in this study. The TAD group consisted of 68 patients, while the non-TAD group was comprised of 42 patients. The mean age of the TAD group was 19.7 years (SD = 8.5 years; range = 10.6 – 68.8 years), 60% were female, and 17 out of 68 (25%) had teeth extracted as part of their orthodontic treatment plan. The mean age of the non-TAD group was 17.5 years (SD = 10.0 years; range = 9.8 – 59.3 years), 76% were female, and 10 out of 42 (23.8%) had teeth extracted. A summary of the demographics of the sample can be found in Table 1.

Pre-treatment (T1) and end-of-treatment (T2) lateral cephalograms were obtained and measured for all 110 individuals. Seventeen patients lacked a millimetric ruler in either one or both of their cephalometric images, so molar calibration was utilized for these individuals. Pre-treatment (T1) intraoral photographs were also collected for all 110 subjects. Post-treatment (T2) intraoral photographs could not be provided for 4 patients; these 4 patients were excluded from T2 POSI analysis, leaving 106 patients eligible for T2 POSI analysis.

Retention (T3) intraoral images were obtained for 58 total patients – 36 TAD patients, and 22 non-TAD patients. POSI analysis was performed on each of these 58 individuals.

The mean pre-treatment (T1) overbite, measured from lateral cephalometric images was -3.0 mm (SD = 2.3 mm) for TAD patients, and -2.1 mm (SD = 1.6) for the non-TAD group. The mean T1 POSI score was 4.8 (SD = 1.3) for the TAD group and 4.2 (SD = 1.4) for the non-TAD group. Lack of vertical overlap of all four incisors (POSI $\geq$ 4) was displayed in 87% of TAD patients (N = 59) and 79% of non-TAD patients (N = 33), indicating significant anterior open bites.

Intra-rater reliability

The Pearson Correlation reliability was between 93.1 – 99.9% for the cephalometric measurements, with Anterior Face Height (N-Me) the most reliable, and Posterior Face Height (Ar – Jarabak Go) the least reliable. The Pearson intra-rater reliability percentage for POSI scoring was 96.5% for T1 and 100% for both T2 and T3.

Treatment Success

From the descriptive analyses, there was an 88.1% success rate for non-TAD patients based on post-treatment (T2) positive overbite (OB > 0) scored from lateral cephalometric measurements. Average amount of OB correction for the non-TAD group was 3.1 mm from T1 (mean OB = -2.1 mm) to T2 (mean OB = 1.0 mm). For the TAD group, a success rate of 83.8% was found, based on lateral cephalometric measurements. Average amount of OB correction for the TAD group was 3.9 mm from T1 (mean OB = -3.0 mm) to T2 (mean OB = 0.9 mm). No significant differences were noted in success rate by treatment group, as shown in Table 2.

The POSI analysis showed 92.9% success rate for the non-TAD group, based on T2 POSI score of zero. These patients demonstrated an average change in POSI score of 4.0 from T1 POSI (4.2) to T2 POSI (0.2). Treatment success from POSI scoring (T2 POSI = 0) was 90.6% for the TAD group. An average change in POSI score of 4.5 from T1 POSI (4.8) to T2 POSI (0.3) was observed for patients treated with TADs. A summary of T1 and T2 POSI scores is presented in Table 3.

Table 4 displays a comparison of all cephalometric variables measured in TAD and non-TAD patients, after adjusting for potential confounding variables such as baseline severity, extractions, gender, age and clinic site. While it appears that distinctions are notable in method of correction between the two groups, statistical significance was only achieved in change in upper molar position relative to the palatal plane (U6-PP).

Treatment Stability

Treatment stability was measured for 58 total patients who were able to provide intraoral photographs at least one year following the completion of orthodontic treatment (average time T2-T3 = 17.97 months). Two of these 58 patients who provided T3 records had unsuccessful treatment at T2 (POSI > 0), and were thus not considered for T3 stability rates. From the remaining sample, stability (T3 POSI = 0) was observed in 71.4% of cases, irrespective of treatment rendered. Stability rates among treatment group are summarized in Table 2.

Patients treated with TADs maintained a stable positive overbite (POSI = 0) in 80% of the cases. Each of the seven TAD patients with relapse after one year had a T1 POSI score of five or greater. Non-TAD patients had a lower – though not statistically significant (P = 0.07) stability rate relative to the TAD group, as 57.1% of non-TAD subjects maintained a POSI of zero after one year. One of the nine non-TAD relapse subjects had a T1 POSI of two, while the remaining subjects had a T1 POSI score of four or greater. Table 5 presents a description of characteristics of both relapse and stable patients. Table 6 more specifically summarizes T2 to T3 POSI scores to demonstrate the degree of relapse exhibited by this sample.

Effects of Growth

Of the 110 total patients included in this study, 39 individuals demonstrated a change of at least 2.5 mm of mandibular length from T1 to T2, indicating growth during treatment. Nineteen (mean age = 14.2 years; range = 10.8 – 17.5 years) of these growing patients had TADs placed as part of their treatment, whereas the other 20 (mean age = 12.6 years; range = 9.8 – 15.4 years) individuals were part of the non-TAD group.

Growing individuals - regardless of whether or not TADs were utilized - had a success rate of 84.6%, compared to the 85.9% success rate in non-growing subjects. Table 7 highlights the cephalometric differences in treatment among growing and non-growing individuals, with or without TADs. Compared to growing patients treated without TADs, growing patients with TADs demonstrated statistically significant differences in change in SNB, lower face height (LFH), total anterior face height (TAFH), posterior face height (PFH), upper molar vertical change, and lower molar vertical change.

A discrepancy in long-term stability is evident between growing individuals versus non-growers, though not statistically significant. Stability of treatment was demonstrated in 50% of growing patients, while 83.3% of non-growing patients maintained stable results long-term. Table 8 provides a summary of treatment success and stability, categorized by growth and use of TADs.

<u>Skeletal Anchorage Location</u>

Utilization of TADs in both upper and lower arches appeared to have an effect on the means of AOB correction. While the millimetric amount of OB correction was not drastically different between the three groups studied (Non-TADs = 3.1 mm; TADs in maxillary arch = 3.8 mm; TADs in both arches = 4.2 mm), differences were noted between groups in vertical skeletal and dentoalveolar changes. Perhaps most notable was the amount of incisor extrusion necessary to correct the OB between groups. An average of 5.6 mm incisor extrusion (upper and lower incisors combined) was seen in the non-TAD group, compared to 3.9 mm extrusion in patients with TADs in the maxillary arch only, and 1.9 mm extrusion in patients with TADs in both arches. A summary of cephalometric findings for patients with no TADs, TADs in one arch, and TADs in both arches is presented in Table 9.

<u>Pre-treatment Severity</u>

From the descriptive analyses, there was a T2 overall cephalometric success rate of 92% (47/51), 89% (33/37), and 63% (14/22) for patients categorized as having mild, moderate, and severe T1 anterior open-bites respectively. Stability rate from POSI analysis at T3 for these same groups was 78% (21/27), 63% (12/19), and 58% (7/12).

The T2 success rate for mild and moderate AOB patients was similar between TAD and non-TAD patients. The success rate for severe AOB patients was actually higher (83.3%) for non-TAD patients than for TAD patients (56.2%).

Treatment stability was found to be higher in TAD patients in both mild and severe T1 AOB groups relative to non-TAD patients, while stability rate was similar among TAD and non-TAD subjects in the moderate category. It should be stressed however, that sample size was small in most tiers at the T3 stability timepoint. A summary of treatment success and stability in relation to pre-treatment severity can be found in Table 10.

Predictive Models

Multivariate models were established to predict treatment success and treatment stability. Both success and stability models were created to compare treatment groups of TADs vs Non-TADs. The results from these predictive models are summarized in Table 11. The predictive model for treatment success had one significant factor with a $P<.05$, which was pre-treatment overbite; the more severe the initial AOB, the less likely the odds were of having successful treatment. There were two significant predictors of treatment stability, being pre-treatment overbite and growth during treatment. Patients with more severe AOB, and those demonstrating growth during treatment had lower likelihood of remaining stable one year after treatment completion.

DISCUSSION

This study evaluates the treatment success and stability of growing and non-growing AOB patients being treated with fixed orthodontic appliances with or without skeletal anchorage.

Considering the difficulty generally associated with correction of AOB malocclusions, the success rate for patients treated with skeletal anchorage (83.8%) and without skeletal anchorage (88.1%) was promising. Differences in success rate were not statistically significant between treatment groups, whether measured by cephalometric success (OB > 0), or POSI success (POSI =0).

Patients in this sample had slightly higher success rates using the POSI analysis compared to cephalometric analysis, whereas the results of a recent study by Huang et al found the POSI analysis to be the more discriminating measure of success.[17] The reasons for this could be multifactorial; if the intraoral photograph is taken from above the occlusal plane and angled downward, it can give the appearance of incisor overlap when there may actually be interocclusal space present. Three patients from this sample were found to have a T2 POSI score of zero, while the corresponding T2 cephalometric radiographs showed persistent openness at the central incisors (average T2 OB = -0.4 mm). Additionally, there were four patients missing T2 photographs, and the decreased sample size seems to have inflated the POSI success rate. When utilizing the POSI analysis, care must be taken in obtaining intraoral photographs that are parallel to and on the same vertical level as the plane of occlusion.

The amount of overbite correction in TAD patients (3.9 mm) was slightly higher than in non-TAD patients (3.1 mm), though not statistically significant. Most patients in this study had open bites that were of skeletal origin, and prior to treatment, the TAD patients especially showed increased propensities toward increased mandibular plane angle (43.2°), increased lower facial height (68.8 mm), and increased anterior facial height (120.9 mm). Non-TAD patients also exhibited increased vertical measurements, though not as severe as their TAD counterparts.

The average amount of maxillary molar intrusion in TAD patients in the present study (-0.9 mm) was slightly less than that of other similar studies (-1.8 to -3.4 mm).[7-10,12,18] The total number of TAD patients in this study is relatively large compared to other similar studies, and the TAD patients were collected from five independent treatment sites. There is bound to be a corresponding wide range of maxillary molar vertical change due to the heterogeneity of treatment locations, and our sample demonstrated that, with a range of 2.1 mm extrusion to 4.4 mm intrusion. This may also be partially due to the fact that the amount of molar intrusion necessary to obtain a positive overbite varies with the severity of pre-treatment open-bite, and the TAD sample in this project had a less severe mean T1 open-bite (-3.0 mm) relative to previously cited studies.

Growth during treatment is another important factor to consider with these findings. For example, Buschang et al found that in growing patients, less molar intrusion is required to achieve desired facial changes (i.e. decrease in mandibular plane angle), as growth aids in these corrections.[19] The same study also determined that *relative* intrusion of lower molars is often sufficient in growing individuals, and that close supervision of overbite and overjet can act as a guide to dictate the need for additional molar intrusion. The results from our sample appear to parallel these findings, as growing patients treated with TADs exhibited less molar intrusion, yet greater decreases in mandibular plane angle compared to non-growing TAD patients.

A project by Hart et al[20] studied 31 patients treated with TADs, with the sample divided by chronological age to assess differences detected by growth potential. Hart concluded that the use of TADs in growing patients acts as a means to offset the underlying vertical growth pattern that occurs during treatment. The present sample tends to concur with these findings. For example, growing patients treated with TADs actually had increases in lower face height (1.4 mm) and total anterior face height (2.4 mm) from baseline to completion of treatment, but had significantly decreased vertical changes relative to the growing patients treated without TADs (LFH = 3.6 mm, TAFH = 5.2 mm). Meanwhile, non-growing patients treated with TADs displayed a decrease in lower face height (-0.6 mm) and total anterior face height (-0.2 mm), while non-growing patients treated without TADs showed slight increases in these values (LFH = 0.8 mm, TAFH = 1.5 mm).

Aside from the influence of growth on treatment, this study also observed the effect of skeletal anchorage used in one arch only, compared to skeletal anchorage utilized in both upper and lower arches. Scheffler et al hypothesized that controlling the vertical position of mandibular molars during the intrusion phase is crucial for obtaining facial and skeletal changes in the vertical dimension in severe long face open bite patients.[7] In the present study, more significant skeletal and facial changes were noted in patients who had TADs utilized in both upper and lower arches, particularly in change in lower face height and anterior face height. Though these results were found to be statistically significant, they should be interpreted cautiously, as only 11 patients from our sample were treated with TADs in both arches, compared to a much larger 57 patients treated with TADs in one arch only.

The use of skeletal anchorage in both arches also reduced the amount of incisor extrusion necessary to correct the open bite. A combined 1.9 mm extrusion (added value of upper and lower incisors) was detected in patients treated with both upper and lower TADs, compared to 3.9 mm combined extrusion in patient treated with TADs in only the maxillary arch. Patients treated without TADs displayed a combined 5.6 mm of incisor extrusion. Limiting incisor extrusion in open bite correction is especially important when patients already exhibit excessive gingival display. Previous studies[8,21] have also found that intrusion tends to be a more stable movement than extrusion of teeth, so limiting the amount of extrusion of incisors may contribute to a more stable correction.

Stability is an important factor to consider in treating open bite patients. Stability of treatment was determined by assessing intraoral photographs at least one year after treatment completion. It is important to recognize that our results may be confounded due to the amount of missing data at the stability timepoint (52/110 missing T3 records).

Previous studies have found that a majority of open bite relapse occurs within the first year following treatment completion. Baek et al[11] reported 80% of relapse occurring during the first year, while Marzouk et al[12] found that 73% of overbite relapse transpired over the first year post-treatment. Considering these findings, we used one-year post-treatment as the cutoff for measurement of stability. We recognize that some relapse is bound to occur after one year of treatment completion, and a requirement of greater time between T2-T3 records would be more representative of actual stability.

The major difference in stability rates among TAD patients (80%) compared to patients treated without TADs (57.1%) was somewhat surprising. The stability rate in our sample of non-TAD patients was lower than that reported in a systematic review by Greenlee et al,[13] who reported a stability rate of 75% among non-surgically treated AOB patients after 12 months of treatment completion. Other studies reported stability findings in TAD treated patients similar to those in our sample.[7,11]

Since stability of treatment was assessed from intraoral photographs and not from T3 lateral cephalographs, it is unknown from this sample what was the main source of relapse, nor what was the millimetric amount of overbite relapse. The stability findings must be regarded with care, as patients were characterized as being "stable" in the retention period if they had a T3 POSI score of zero, meaning any amount of positive overlap of all anterior teeth. Therefore, stability in this study should not be interpreted as total lack of vertical relapse.

A study conducted by Deguchi et al reported that extrusion of lower molars appeared to be most responsible relapse findings in adult open bite patients treated with TADs.[9] Additional reports confirm that re-eruption of molars is to be expected after removal of skeletal anchorage.[7,11] To counteract this, practitioners could consider over-intruding molars until a posterior open-bite is established, and/or maintain TADs for a holding effect for a period of time during the retention phase.

The stability of extruded incisors remains questionable, as many studies have shown mixed results. Marzouk[12] and Sugawara et al[22] found relative stability of incisor extrusion, whereas Scheffler[7] reported post-treatment intrusion of incisors, even up to 2 mm in a small part of her sample. Others, including Baek et al,[11] have reported additional incisor extrusion post-treatment in the form of settling.

Though the mode of open-bite relapse remains uncertain, the rate of stability in the patients treated with skeletal anchorage in our sample was encouraging. Of the 16 patients from our sample that relapsed, 12 (75%) had a T3 POSI score of one or two, while the remaining four patients had a T3 POSI score of three or four. In our sample, based on photographic evaluation, the degree of relapse was mild.

The effect of pre-treatment open bite severity on success and stability is inconclusive. Subjects with severe open bites that were treated with TADs had lower success rates and higher (worse) mean POSI scores at treatment completion. However, the opposite trend was seen in the stability stage, as pre-treatment severity appeared to have less of an effect on stability in TAD patients compared to those treated without TADs. The quantity of stability records for each group continued to diminish as TAD and non-TAD subgroups were further divided into mild, moderate, and severe categories. Thus, the interpretation of these findings is guarded. Previous studies limited to TAD patients have also had mixed results regarding the influence of pre-treatment severity on relapse potential. Marzouk[12] found that relapse was positively correlated with initial open bite severity, while Baek[11] and Lee and Park[23] found a negative correlation between overbite relapse and pre-treatment severity.

Growth must be considered as an important factor in the stability of treated patients, whether or not skeletal anchorage is utilized. The higher relapse rate in non-TAD patients in the current sample could perhaps further be explained by the greater proportion of the TAD patients exhibiting no growth during treatment. A further breakdown of our sample showed that stability of treatment was maintained in only 50% of growing patients compared to 83.3% stability in non-growers. Furthermore, growers comprised only 25% of the patients found to have positive overbite in the retention stage, whereas growing patients comprised 62.5% of the relapse sample. Scheffler[7] reported that changes found in patients in post-retention from her sample were attributable to growth rather than relapse in tooth position.

The present study benefited from having controls in both growing and non-growing open bite patients to evaluate the effects of TADs, with long-term follow-up records. Future studies assessing success and stability in growing and non-growing open bite patients treated with or without skeletal anchorage should include larger treatment subgroups with a more homogenous treatment site and technique. A more complete set of retention records with increased follow-up time would provide an improved representation of stability findings. A prospective study would also provide more impactful analysis of patients treated in a similar manner.

LIMITATIONS

There were several limitations to our study. First and foremost was the selection of the sample, which was not randomized. The sample from the University of Washington database was reviewed for consecutively treated open bite patients. However, due to varying quality and completeness of records, not every patient treated for open bite was able to be included. Numerous additional practitioners were recruited by the primary investigator, but a small percentage of those recruited volunteered to participate. It is possible that the practitioners who did participate have a high level of interest or confidence in treating AOB malocclusions and may not be representative of the general orthodontist population. Additionally, there was no way to verify that consecutively treated patients were shared. Thus, the potential for selection bias is high. Participating practitioners were also asked to contribute patients treated both with and without skeletal anchorage, but most only contributed patients with one method of treatment. A range of practitioners also presents a lack of standardization of treatment, even within treatment groups.

Another limitation is in the analysis and scoring of the provided records. With POSI scoring, parallax error in intraoral photos could skew the appearance of vertical overlap of incisors. The small, yet present disharmony between treatment success as measured by radiographs and photographs brings the accuracy of the success rates into question. We estimated that 2.7% of the T2 photos appeared to be taken from above or below the occlusal plane, however no photos were so extreme that they were excluded from analysis. Only POSI scoring was completed for the stability time point, and the potential for small measurement error in the stability records must be acknowledged. Though reliability measurements were high in the radiographic analysis, it is important to recognize the 17 patients who were missing millimetric rulers for calibration. There is an inherent risk for measurement error in using molars for calibration as opposed to a millimetric ruler. First is that the molars can often overlap and can be challenging to confidently identify. Additionally, any error in a small calibration measurement has the potential to be amplified.

Missing records, particularly at the stability timepoint is a possible confounder of findings. Not only did the decreased sample size at T3 affect the power of our results, but it was not always known whether T3 records weren't shared because of unavailability, or because of selection bias.

There are other variables that may have had an effect on our results. This study does not account for pre- or post-treatment habits nor the type of retention utilized. Other factors such as condylar pathologies were not assessed. Treatment length was not evaluated, which could also be a confounding factor.

CONCLUSIONS

This study demonstrated that treatment success rates were high for patients treated orthodontically for anterior open bite. Beneficial vertical changes can be obtained with the use of skeletal anchorage for molar intrusion in open bite patients, particularly when it is utilized in both upper and lower arches. This is seen most notably in change in lower face height, total anterior face height, and in limiting incisor extrusion. Open bite patients with growth potential may also benefit from the use of TADs during treatment, as it appears to limit the vertical growth pattern normally expected. Practitioners should be aware of the relapse potential in open bite patients, especially in growing patients. Further studies are required to conclusively determine the effects of growth and retention protocol on stability in patients treated for open bite.

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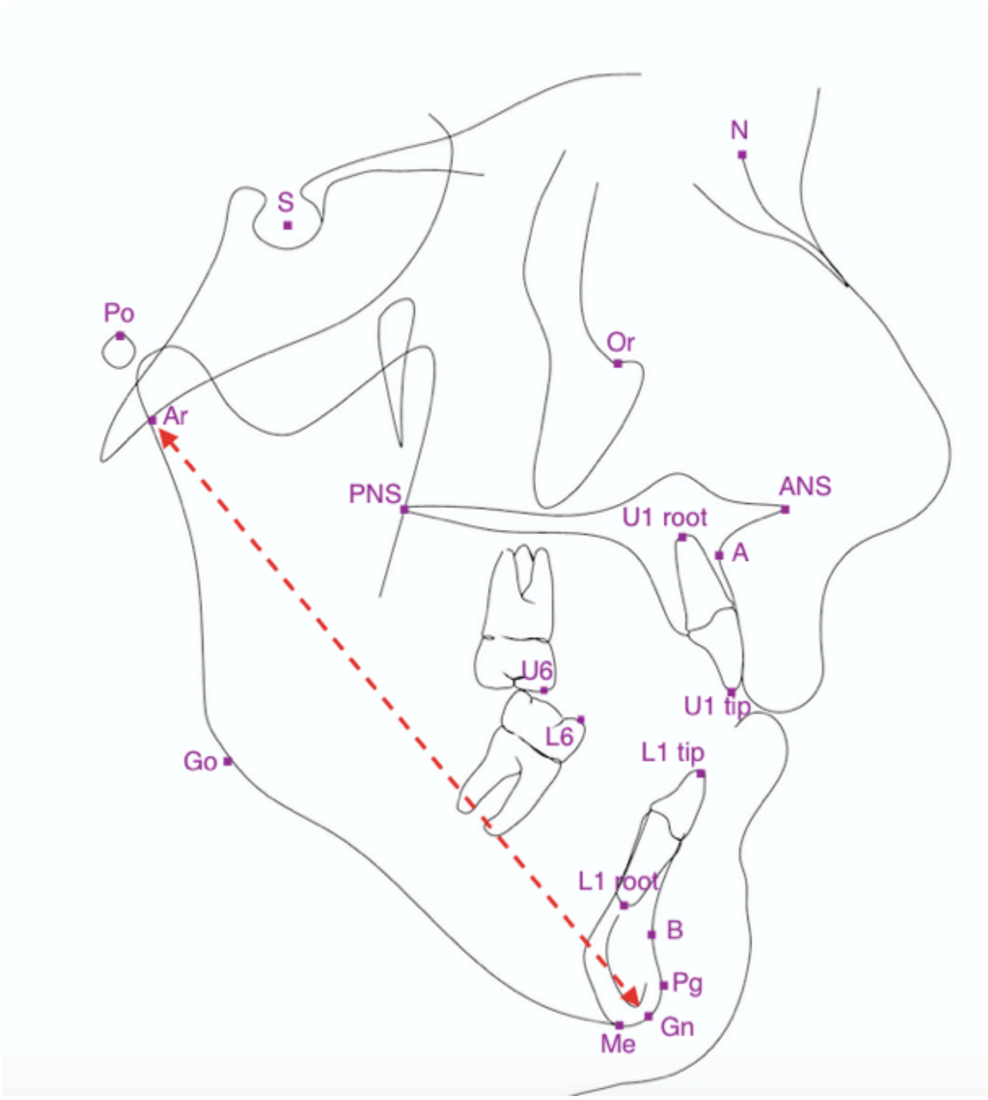

Figure 1. Cephalometric landmarks identified on pre- and post-treatment lateral cephalographic images: sella (S), nasion (N), porion (Po), orbitale (Or), articulare (Ar), posterior nasal spine (PNS), anterior nasal spine (ANS), gonion (Go), A-point (A), B-point (B), pogonion (Pg), gnathion (Gn), menton (Me), incisal edge of the maxillary incisor (U1 tip), root tip of the maxillary incisor (U1 root), incisal edge of the mandibular incisor (L1 tip), root tip of the mandibular incisor (L1 root), mesiobuccal cusp tip of the maxillary first molar (U6), mesiobuccal cusp tip of the mandibular first molar (L6).
Mandibular length is demonstrated by dotted line from articulare (Ar) to gnathion (Gn).

Figure 2. Photographic Open-bite Severity Index (POSI)

1. One or two maxillary lateral incisors without vertical overlap

2. One maxillary central incisor without vertical overlap

3. Both maxillary central incisors without vertical overlap

4. All four maxillary incisors without vertical overlap

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

6. All anterior teeth, plus at least one premolar, without vertical overlap

Table 1. Patient demographics

	Non-TAD N = 42		TAD N = 68	
	Non-grower N = 22	Grower N = 20	Non-grower N = 49	Grower N = 19
Age - Mean (SD)	19.6 (12.2)	12.6 (1.4)	20.6 (9.1)	14.2 (2.2)
Extractions	N = 22	N = 20	N = 49	N = 19
Yes	4 (18.2 %)	6 (30 %)	14 (28.6 %)	2 (10.5 %)
No	18 (81.8 %)	14 (70 %)	35 (71.4 %)	17 (89.5 %)
Gender	N = 22	N = 20	N = 49	N = 19
Male	4 (18.2 %)	5 (25 %)	16 (32.7 %)	11 (57.9 %)
Female	18 (81.8 %)	15 (75 %)	33 (67.3 %)	8 (42.1 %)
Treatment site	N = 22	N = 20	N = 49	N = 19
University of Washington	13 (59.1 %)	16 (80 %)	5 (10.2 %)	2 (10.5 %)
Private practice	9 (40.1 %)	4 (20 %)	44 (89.8 %)	17 (89.5 %)
Practitioner	N = 22	N = 20	N = 49	N = 19
Practitioner A	0 (0 %)	1 (5 %)	4 (8.2 %)	9 (47.4 %)
Practitioner B	0 (0 %)	0 (0%)	8 (16.3 %)	1 (5.3 %)
Practitioner C	0 (0 %)	0 (0%)	30 (61.2 %)	7 (36.8 %)
Practitioner D	0 (0 %)	0 (0%)	1 (2.0 %)	0 (0 %)
Practitioner E	4 (18.2 %)	3 (15 %)	0 (0 %)	0 (0 %)
Practitioner F	5 (22.7 %)	0 (0%)	0 (0 %)	0 (0 %)

[1]Percents are "column" %s, namely the proportion of the variable (row heading) for that treatment group

Table 2. Success and Stability – TADs vs. Non-TADs

Success and stability	TADs	No TADs	P
N (Total = 110)	68	42	
Cephalometric analysis			
T1 mean (SD) OB	-3.0 (2.3)	-2.1 (1.6)	
T2 mean (SD) OB	0.9 (1.2)	1.0 (0.9)	0.2
T2 success (OB > 0) n/N	57/68	37/42	
T2 success (OB > 0) %	83.80%	88.10%	0.5
POSI analysis			
T1 mean (SD) POSI	4.8 (1.3)	4.2 (1.4)	
T2 mean (SD) POSI	0.3 (1.2)	0.2 (0.7)	0.3
T2 success (POSI = 0) n/N	58/64*	39/42	
T2 success (POSI = 0) %	90.60%	92.90%	0.7
POSI stability			
T3 mean (SD) POSI	0.4 (0.9)	1.0 (1.4)	0.2
T3 stability (POSI = 0) n/N	28/35	12/21	
T3 stability (POSI = 0) %	80.00%	57.14%	0.07

[1]Four subjects did not have T2 photographs, and are therefore lacking T2 POSI scores

[2]P-values adjusted for baseline severity, extractions, gender, age, and clinic site.

Table 3. Pre-treatment (T1) and post-treatment (T2) POSI scores

All patients

POSI at T1	# of patients	POSI at T2 0	1	2	3	4	5	6
1	3	3	0	0	0	0	0	0
2	8	8	0	0	0	0	0	0
3	6	6	0	0	0	0	0	0
4	26	25	0	0	0	1	0	0
5	32	30	1	0	0	0	1	0
6	31	25	2	2	0	0	0	2
total	106	97	3	2	0	1	1	2

Frequency missing at T2 = 4

No TADs

POSI at T1	# of patients	POSI at T2 0	1	2	3	4	5	6
1	2	2	0	0	0	0	0	0
2	4	4	0	0	0	0	0	0
3	3	3	0	0	0	0	0	0
4	17	16	0	0	0	1	0	0
5	8	8	0	0	0	0	0	0
6	8	6	0	2	0	0	0	0
total	42	39	0	2	0	1	0	0

TADs

POSI at T1	# of patients	POSI at T2 0	1	2	3	4	5	6
1	1	1	0	0	0	0	0	0
2	4	4	0	0	0	0	0	0
3	3	3	0	0	0	0	0	0
4	9	9	0	0	0	0	0	0
5	24	22	1	0	0	0	1	0
6	23	19	2	0	0	0	0	2
total	64	58	3	0	0	0	1	2

Frequency missing at T2 = 4

Table 4. Cephalometric measurements – baseline (T1) and change (T1-T2)

Cephalometric analysis		No TADs Baseline (T1) Mean (SD)	No TADs Change (T1-T2) Mean (SD)	TADs Baseline (T1) Mean (SD)	TADs Change (T1-T2) Mean (SD)
Skeletal					
Maxilla to cranial base	SNA (º)	80.3, (4.5)	-0.5, (1.4)	79.8, (5.0)	-0.4, (1.0)
Mandible to cranial base	SNB (º)	76.9, (3.5)	-0.3, (1.2)	74.9, (5.3)	0.3, (0.9)
Maxilla to Mandible	ANB (º)	3.4, (3.1)	-0.2, (0.9)	4.9, (2.7)	-0.7, (1.1)
Mandibular plane angle	MP - SN (º)	39.5, (5.8)	0.2, (1.9)	43.2, (7.3)	-1.0, (1.4)
Cranio-Mx Base	N, S, ANS, PNS (º)	7.8, (3.3)	0.6, (1.5)	8.5, (3.8)	0.2, (0.9)
Upper Face	N, Me, ANS, PNS (mm)	49.7, (4.2)	1.1, (1.8)	52.1, (3.9)	0.5, (0.9)
Lower Face	N, Me, ANS, PNS (mm)	64.7, (6.2)	2.2, (2.2)	68.8, (6.1)	0.0, (2.0)
Anterior face height	Na-Me (mm)	114.4, (9.4)	3.3, (3.4)	120.9, (8.7)	0.5, (2.3)
Posterior facial height	Ar, *Jarabak Go (mm)	43.6, (5.8)	2.5, (2.3)	43.2, (5.3)	1.3, (1.6)
Dento-alveolar					
Upper incisor	U1-Na (mm)	6.4, (3.0)	-1.3, (2.8)	4.3, (2.3)	-2.0, (2.7)
	U1 - Na (º)	28.3, (7.4)	-3.2, (7.7)	24.5, (7.1)	-4.1, (8.1)
Lower incisor	L1 - NB (mm)	6.9, (3.1)	0.2, (1.8)	5.9, (2.9)	-0.1, (2.2)
	L1 - NB (º)	31.4, (8.1)	-1.8, (5.7)	28.1, (7.5)	-0.6, (6.1)
	IMPA (º)	94.9, (8.1)	-1.7, (5.8)	90.0, (7.4)	0.1, (5.9)
Overbite	Occ plane distal, U1 tip, U1L1 bisection (mm)	-2.1, (1.6)	3.1, (1.8)	-3.0, (2.3)	3.9, (2.4)
Overjet	Occ Plane distal, U1 tip, L1 tip, U1L1 bisection (mm)	3.7, (2.4)	-1.1, (2.4)	5.1, (2.6)	-2.4, (2.6)
Upper molar vertical change	U6 - SN-7 (mm)	-63.1, (5.6)	-1.9, (2.0)	-66.5, (4.6)	0.4, (1.6)
	U6 - PP (UPDH) (mm)	22.4, (3.0)	1.1, (1.1)	24.2, (2.6)	-0.8, (1.4)*
Lower molar vertical change	L6 - MP (mm)	30.7, (3.5)	1.6, (1.3)	31.5, (3.7)	1.1, (1.1)
Upper incisor vertical change	U1 Tip - SN-7 (mm)	-68.5, (5.9)	-3.4, (2.5)	-71.3, (5.4)	-2.5, (1.9)
	U1 - PP (UADH) (mm)	27.4, (3.0)	2.3, (1.4)	28.3, (3.4)	2.0, (1.6)
Upper incisor	U1 - PP (º)	116.4, (7.4)	-3.0, (7.9)	113.0, (7.0)	-4.4, (7.7)
Lower incisor vertical change	L1 - MP (LADH) (mm)	39.1, (4.0)	2.2, (1.4)	40.1, (4.1)	1.1, (1.6)
Mandibular length	Ar - Gn (mm)	101.0, (7.1)	2.9, (2.6)	103.4, (7.2)	1.8, (1.8)

* Significant difference between treatment groups (P <0.05)
[1]P-values adjusted for baseline severity, extractions, gender, age, and clinic site.

Table 5. Characteristics of stable vs. relapse patients

	Stable (T3 POSI = 0)	Relapse (T3 POSI > 0)
N	40	16
T1 cephalometric values		
SN-MP (º)	42.5 (7.5)	40.3 (7.5)
Lower Face Height (mm)	67.7 (5.9)	65.2 (5.5)
Anterior Face Height (mm)	119.4 (7.5)	116.1 (8.3)
U1-NA (º)	23.9 (7.1)	30.8 (7.7)
IMPA (º)	91.1 (7.6)	94.3 (9.9)
Overbite (mm)	1.9 (1.6)	2.7 (1.6)
Patient demographics	N = 40	N = 16
TAD patients	28 (70.0%)	7 (43.8%)
Non-TAD patients	12 (30.0%)	9 (56.2%)
Extractions	12 (30.0%)	4 (25.0%)
Male	7 (17.5%)	7 (43.8%)
Female	33 (82.5%)	9 (56.2%)
Grower	10 (25.0%)	10 (62.5%)
Academic Institution	11 (27.5%)	8 (50.0%)
Private practice	29 (72.5%)	8 (50.0%)
Age - Mean (SD)	18.6 (6.0)	13.8 (2.0)
Severity of Relapse	N = 40	N = 16
T3 POSI = 1-2	N/A	12 (75.0%)
T3 POSI = 3-4	N/A	4 (25.0%)
T3 POSI = 5-6	N/A	0 (0.0%)

[1]Two patients with T3 records had unsuccessful treatment (T2 POSI > 0) and were thus not considered in either the "stable" or "relapse" categories.

Table 6. Post-treatment (T2) and retention (T3) POSI scores

No TADs

POSI at T2	# of patients	**POSI at T3**						
		0	**1**	**2**	**3**	**4**	**5**	**6**
0	21	12	5	1	1	2	0	0
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	1	0	0	0	0	1	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
total	22	12	5	1	1	3	0	0

TADs

POSI at T2	# of patients	**POSI at T3**						
		0	**1**	**2**	**3**	**4**	**5**	**6**
0	35	28	5	1	1	0	0	0
1	1	0	0	0	0	1	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
total	36	28	5	1	1	1	0	0

Frequency missing at T3 = 52

Table 7a. Cephalometric changes for non-growing patients

	Non-growers			
	No TADs		TADs	
	Baseline (T1)	Change (T1-T2)	Baseline (T1)	Change (T1-T2)
Ceph analysis	Mean (SD)		Mean (SD)	
SNA (º)	80.0 (4.7)	-0.1 (1.1)	79.7 (5.0)	-0.3 (0.8)
SNB (º)	77.1 (3.5)	-0.4 (1.1)	74.7 (5.5)	0.1 (0.8)
ANB (º)	2.9 (3.2)	0.3 (0.5)	4.9 (2.9)	-0.4 (0.9) *
MP - SN (º)	38.6 (5.6)	0.4 (1.4)	43.3 (7.6)	-0.9 (1.1) *
N, S, ANS, PNS (º)	8.1 (3.4)	0.5 (1.1)	8.6 (3.7)	0.2 (0.9)
N, Me, ANS, PNS (mm)	50.1 (3.9)	0.6 (0.9)	52.1 (3.8)	0.3 (0.7)
N, Me, ANS, PNS (mm)	65.2 (6.5)	0.8 (1.8)	68.8 (6.2)	-0.6 (1.6) *
Na-Me (mm)	115.3 (9.6)	1.5 (2.0)	120.9 (8.6)	-0.2 (1.7) *
Ar, *Jarabak Go (mm)	44.6 (5.8)	1.1 (2.2)	43.3 (5.4)	0.7 (1.1)
U1-Na (mm)	5.6 (2.8)	-1.2 (2.7)	4.3 (2.0)	-2.3 (2.7)
U1 - Na (º)	26.3 (6.8)	-1.5 (7.5)	24.7 (7.3)	-4.8 (8.0)
L1 - NB (mm)	6.3 (2.9)	0.3 (2.1)	5.9 (3.1)	-0.1 (2.4)
L1 - NB (º)	29.7 (8.5)	-0.5 (6.2)	27.9 (8.2)	-0.5 (6.5)
IMPA (º)	94.0 (8.8)	-0.5 (6.1)	89.8 (8.0)	0.3 (6.3)
Overbite (mm)	-2.0 (1.5)	3.1 (1.8)	-2.9 (1.8)	3.7 (2.0)
Overjet (mm)	3.0 (2.2)	-0.5 (2.3)	5.2 (2.8)	-2.3 (2.7) *
U6 - SN-7 (mm)	-63.8 (5.7)	-0.9 (1.1)	-66.4 (4.6)	0.8 (1.3) *
U6 - PP (UPDH) (mm)	22.7 (3.1)	0.5 (0.9)	24.2 (2.7)	-1.1 (1.2) *
L6 - MP (mm)	31.0 (3.8)	0.9 (1.1)	31.7 (4.0)	0.9 (1.1)
U1 Tip - SN-7 (mm)	-68.9 (5.7)	-2.5 (1.6)	-71.4 (5.2)	-2.0 (1.7)
U1 - PP (UADH) (mm)	27.2 (2.9)	1.8 (1.3)	28.4 (3.5)	1.7 (1.6)
U1 - PP (º)	114.4 (5.9)	-1.1 (7.7)	112.9 (7.6)	-4.9 (8.0)
L1 - MP (LADH) (mm)	38.7 (4.1)	1.8 (1.3)	40.1 (4.0)	0.7 (1.5) *
Ar - Gn (mm)	102.5 (7.5)	1.0 (0.8)	102.9 (7.3)	0.8 (0.8)

Table 7b. Cephalometric changes for growing patients

	Growers			
	No TADs		TADs	
	Baseline (T1)	Change (T1-T2)	Baseline (T1)	Change (T1-T2)
Ceph analysis	Mean (SD)		Mean (SD)	
SNA (º)	80.7 (4.2)	-1.0 (1.5)	80.2 (5.3)	-0.6 (1.5)
SNB (º)	76.8 (3.6)	-0.3 (1.4)	75.5 (4.8)	0.8 (1.1) *
ANB (º)	3.9 (3.0)	-0.7 (1.0)	4.7 (2.0)	-1.4 (1.4)
MP - SN (º)	40.6 (5.9)	0.0 (2.3)	42.8 (6.8)	-1.3 (1.9)
N, S, ANS, PNS (º)	7.5 (3.2)	0.8 (1.9)	8.5 (4.1)	0.2 (1.2)
N, Me, ANS, PNS (mm)	49.2 (4.6)	1.6 (2.3)	52.0 (4.3)	0.9 (1.3)
N, Me, ANS, PNS (mm)	64.2 (6.0)	3.6 (1.8)	68.8 (6.1)	1.4 (2.3) *
Na-Me (mm)	113.5 (9.2)	5.2 (3.6)	120.8 (9.0)	2.4 (2.5) *
Ar, *Jarabak Go (mm)	42.4 (5.8)	3.9 (1.4)	43.2 (5.4)	2.8 (1.7) *
U1-Na (mm)	7.2 (3.1)	-1.5 (2.9)	4.3 (2.8)	-1.0 (2.7)
U1 - Na (º)	30.5 (7.6)	-4.9 (7.7)	24.0 (6.9)	-2.2 (8.2)
L1 - NB (mm)	7.6 (3.3)	0.0 (1.5)	5.7 (2.7)	0.2 (1.7)
L1 - NB (º)	33.3 (7.4)	-3.3 (4.8)	28.7 (5.4)	-0.9 (5.0)
IMPA (º)	95.9 (7.5)	-3.0 (5.2)	90.4 (5.7)	-0.4 (4.9)
Overbite (mm)	-2.2 (1.8)	3.1 (1.8)	-3.4 (3.3)	4.4 (3.3)
Overjet (mm)	4.4 (2.4)	-1.8 (2.4)	4.9 (2.3)	-2.5 (2.4)
U6 - SN-7 (mm)	-62.5 (5.7)	-3.0 (2.2)	-66.6 (4.6)	-0.7 (1.8) *
U6 - PP (UPDH) (mm)	22.1 (2.9)	1.8 (1.0)	24.3 (2.5)	-0.1 (1.6) *
L6 - MP (mm)	30.3 (3.3)	2.4 (1.1)	30.9 (2.8)	1.6 (1.0) *
U1 Tip - SN-7 (mm)	-68.1 (6.3)	-4.4 (2.9)	-71.2 (6.0)	-3.7 (1.7)
U1 - PP (UADH) (mm)	27.5 (3.2)	2.9 (1.2)	28.3 (3.2)	2.7 (1.6)
U1 - PP (º)	118.7 (8.4)	-5.2 (7.8)	113.2 (5.3)	-3.0 (6.9)
L1 - MP (LADH) (mm)	39.5 (4.0)	2.7 (1.4)	40.0 (4.2)	2.1 (1.5)
Ar - Gn (mm)	99.4 (6.4)	5.1 (2.1)	104.4 (7.3)	4.1 (1.4)

Table 8. Success and stability in relation to TADs and growth

Success and stability	Non-growers No TADs	Non-growers TADs	Growers No TADs	Growers TADs	P
N (Total = 110)	22	49	20	19	
Pre-treatment (T1)					
Mean (SD) OB (ceph)	-2.0 (1.5)	-2.9 (1.8)	-2.2 (1.8)	-3.4 (3.3)	
Mean (SD) POSI	3.8 (1.2)	4.9 (1.2)	4.5 (1.5)	4.6 (1.5)	
Post-treatment (T2)					
Mean (SD) OB (ceph)	1.1 (1.0)	0.8 (1.4)	0.9 (0.8)	1.0 (0.8)	0.28
Success (OB > 0) n/N (ceph)	21/22	40/49	16/20	17/19	
Success (OB > 0) % (ceph)	95.50%	81.60%	80.00%	89.50%	0.11
Mean (SD) POSI	0.2 (0.9)	0.4 (1.4)	0.2 (0.6)	0.1 (0.3)	0.81
Success (POSI = 0) n/N	21/22	42/46	18/20	16/18	
Success (POSI = 0) %	95.50%	91.30%	90.00%	88.90%	0.85
Retention (T3)					
Mean (SD) POSI	0.9 (1.7)	0.3 (0.7)	1.1 (1.3)	0.8 (1.3)	0.42
Stability (POSI = 0) n/N	7/9	23/27	5/12	5/8	
Stability (POSI = 0) %	77.78%	85.20%	41.70%	62.50%	0.88

Table 9. Cephalometric changes – No TADs, TADs in one arch, TADs in both arches

Cephalometric analysis	No TADs N = 42	TADs - one arch N = 57	TADs - both arches N = 11	P
Mandibular plane rotation MP – SN (º)	0.2	-0.9	-1.4	0.129
Lower Face Height N, Me, ANS, PNS (mm)	2.2	0.2	-1.0	0.049
Anterior Face Height N – Me (mm)	3.3	0.7	-0.4	0.024
Overbite Occ. Plane, U1/L1 bisection (mm)	3.1	3.8	4.2	0.159
Upper molar extrusion U6 – SN-7 (mm)	1.9	-0.4	-0.6	0.076
Lower molar extrusion L6 – MP (mm)	1.6	1.2	0.7	0.127
Upper incisor extrusion U1 tip – SN-7 (mm)	3.4	2.7	1.3	0.026
Lower incisor extrusion L1 tip - MP (mm)	2.2	1.2	0.6	0.109
Combined incisor extrusion U1 tip – SN-7 + L1 tip – MP (mm)	5.6	3.9	1.9	

Table 10. Pre-treatment severity

	Non-TADs			TADs			
	Mild (0 to -2 mm)	Moderate (-2.1 to -4 mm)	Severe (≤ -4 mm)	Mild (0 to -2 mm)	Moderate (-2.1 to -4 mm)	Severe (≤ -4 mm)	P
N	27	10	6	24	27	16	
Pre-treatment (T1)							
Mean (SD) OB (ceph)	-1.1 (0.5)	-2.8 (0.6)	-5.2 (1.1)	-1.2 (0.5)	-2.9 (0.5)	-6.3 (2.2)	
Mean (SD) POSI	3.9 (1.5)	4.3 (0.9)	5.2 (1.0)	4.3 (1.4)	5.1 (1.1)	5.4 (0.6)	
Post-treatment (T2)							
Mean (SD) OB (ceph)	0.9 (1.0)	1.3 (0.8)	0.8 (0.8)	1.2 (0.8)	0.8 (1.4)	0.3 (1.3)	0.25
Success (OB > 0) n/N (ceph)	24/27	9/10	5/6	23/24	24/27	9/16	
Success (OB > 0) % (ceph)	88.9%	90.0%	83.3%	95.8%	88.9%	56.2%	0.39
Mean (SD) POSI	0.3 (0.9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (1.2)	0.9 (1.3)	0.0004
Success (POSI = 0) n/N	24/27	10/10	6/6	23/23	24/26	11/15	
Success (POSI = 0) %	88.9%	100.0%	100.0%	100.0%	92.3%	73.3%	0.01
Retention (T3)							
Mean (SD) POSI	0.9 (1.5)	0.7 (1.2)	1.5 (1.7)	0.0 (0.0)	0.5 (0.8)	0.8 (1.5)	0.03
Stability (POSI = 0) n/N	9/15	2/3	1/4	12/12	10/16	6/8	
Stability (POSI = 0) %	60.0%	66.7%	25.0%	100.0%	62.5%	75.0%	0.68

Table 11. Multivariate predictive models for treatment success and stability

Treatment Success (TADs vs Non-TADs)

	Odds Ratio	P-value
TADs vs Non-TADs	0.85	0.79
Grower	0.99	0.98
Baseline OB (mm)	1.31	0.03
Baseline SN-MP	1.04	0.39

Treatment Stability (TADs vs Non-TADs)

	Odds Ratio	P-value
TADs vs Non-TADs	3.04	0.11
Grower	0.26	0.04
Baseline OB (mm)	1.54	0.02
Baseline SN-MP	1.06	0.26

Table 12. Missing data demographics

T3 Data	Missing	Available
N	52	58
Number in TADs Group	32 (61.5%)	36 (62.1%)
Extract	11 (21.2%)	16 (27.6%)
Male	21 (40.4%)	15 (25.9%)
Female	31 (59.6%)	43 (74.1%)
Grower	18 (34.6%)	21 (36.2%)
Academic Institution	16 (30.8%)	20 (34.5%)
Private practice	36 (69.2%)	38 (65.5%)
Age - Mean (SD)	20.4 (11.7)	17.5 (5.8)