The National Dental Practice-Based Research Network Adult Anterior Openbite Study: Treatment Success

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Abstract

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Introduction: Anterior openbite (AOB) continues to be a challenging malocclusion for orthodontists to treat and retain long-term. There are many orthodontic treatment modalities used to treat AOB in adult patients, but there is no consensus on which modalities are most successful. This study aims to identify the overall success rate of AOB orthodontic treatment in the adult population across the United States, as well as factors that influence treatment success. **Methods:** Practitioners and their adult AOB patients were recruited through the National Dental PBRN. Patient dentofacial and demographic characteristics, practitioner demographic and practice characteristics, and factors relating to orthodontic treatment were reported. Treatment success was determined from post-treatment lateral cephalometric films and intraoral frontal photos. Treatment was categorized into four main groups: aligners, fixed appliances, TADs and

orthognathic surgery. Extractions were also evaluated. Univariate and multivariate models were used to evaluate how treatment success varies with treatment modality, pre-treatment dentofacial characteristics, and patient and practitioner demographic and practice characteristics.

Results: End of active treatment data was collected from 84 practitioners and 254 patients. Eighty four percent of patients finished with positive vertical overlap of all incisors and 93% with positive overbite on the post-treatment lateral cephalogram. While there were no statistically significant differences in success rates between the treatment groups, patients treated with orthognathic surgery had an increased odds for success when compared to those treated with fixed appliances only. Treatment success was also associated with academic practice setting, pre-treatment IMPA ≤90°, no to mild pre-treatment crowding, and treatment duration < 30 months.

Conclusion: The success of orthodontic treatment in adult AOB patients who participated in this study was very high. While there was a range of success for the major treatment modalities, orthognathic surgery was the only treatment modality that reached statistically significance. There were some pre-treatment dentofacial characteristics and treatment factors associated with successful closure of AOB.

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INTRODUCTION

Anterior open bite (AOB) is defined by a lack of vertical overlap between the incisal edges of the maxillary and mandibular teeth. The prevalence of AOB has been reported to range between 0.6% and 16.5%, varying by ethnic group, age, and stage of dentition.[1] This malocclusion can have significant functional and psychological effects on patients. Patients with AOB may have difficulty incising food and enunciating certain phonemes, due to the altered tongue position on the incisors and the anterior hard palate. Furthermore, AOB development is often associated with unfavorable growth patterns, oral habits (i.e., digit sucking and tongue posture), and nasopharyngeal airway obstructions.[2] Due to its complex and multifactorial etiology, AOB continues to be one of the most challenging malocclusions for orthodontists to successfully treat and retain long-term.

Patients with AOB can be treated using a variety of orthodontic treatment modalities. Standard edge-wise fixed appliances (FA) are commonly recommended for patients with AOB.[3] Fixed appliances with vertical elastics or extrusion archwires can create overlap between maxillary and mandibular incisors through incisor extrusion, however, this may lead to increased gingival display and is associated with a high potential for relapse.

In some cases, practitioners may elect to treat AOB patients with orthognathic surgery (SX), especially when a non-growing, adult patient presents with an AOB that is of skeletal origin. Surgery may involve the maxilla, mandible, or both to skeletally correct the AOB.[4]

The use of temporary anchorage devices (TADs) has become an increasingly popular non-surgical technique for correcting AOB.[5] Mini-screws or mini-plates are used to provide anchorage for molar and premolar intrusion. Several case reports have shown TAD molar intrusion to be as successful as orthognathic surgery, suggesting a less invasive and less costly alternative to surgery.[6]

Clear aligners are an esthetic treatment alternative to traditional fixed appliances for AOB. The thickness of the plastic on the occlusal surfaces in combination with the forces of mastication are believed to produce an intrusive force on the posterior dentition and thought to aid in AOB closure.[7,8] Although several case studies have demonstrated successful AOB correction, molar intrusion has not been confirmed.[9,10]

Extractions of premolars, and in some cases molars, may be recommended for AOB correction, especially in the presence of crowding. Premolar extractions are used to create space for greater incisor retraction and uprighting to close the AOB through what is often referred to as the "draw-bridge" effect.[11,12] Molar extractions remove the most distal occlusal stop and create space to move the posterior segment anteriorly ("wedge effect"), resulting in a closing rotation of the mandible.[5,13]

Although there are a variety of orthodontic treatment modalities used to correct AOB in adults, there is still no consensus on what method(s) are most successful.[14-16] A better understanding of the success rates for these treatments, as well as other factors that may influence treatment outcome, would greatly aid clinicians in the management of these patients.

The National Dental Practice-Based Research Network (PBRN) Anterior Openbite Study was launched in 2015. The purpose of this large, prospective cohort study was to explore treatment recommendations, outcomes, and stability of adult ABO patients. This publication reports on the overall success rate of AOB treatment, and explores how treatment success varies with treatment modality, pre-treatment dentofacial characteristics, and patient and practitioner demographic and practice characteristics.

MATERIALS AND METHODS

Dental providers and their adult AOB patients were recruited from six regions of the National Dental PBRN (West, Midwest, Southwest, South Central, South Atlantic and Northeast). Institutional Review Board (IRB) approval was obtained from the University of Alabama IRB (acting as the Central IRB), the Kaiser Permanente IRB (for the Western region), and the University of Rochester Research Subjects Review Board (for the Northeastern region).

Practitioners:

Inclusion criteria for practitioners:

- Is an orthodontist or a dentist that routinely performs orthodontic treatment.
- Estimates he/she can recruit three to eight adult patients in active treatment for AOB, and expects to have treatment completed within 24 months of enrollment into the study.
- Routinely takes cephalometric radiographs (cephalogram) before and after treatment.
- Has the ability to upload de-identified cephalogram and digital intraoral frontal photographs to a central data repository.

- Affirms that the practice can devote sufficient time in patient scheduling to allow recording of all data required for the study.
- Does not anticipate retiring, selling the practice, or moving during the study.

Patients:

Inclusion Criteria for Patients:

- Must be at least 18 years of age at time or enrollment.
- Must have AOB that is defined as one or more incisors that do not have vertical overlap with teeth in the opposing arch. The remaining incisors may have minimal incisor overlap, but none can contact teeth in the opposing arch. This is determined by examining the patient's initial cephalogram, intra-oral photographs, and/or initial plaster or digital casts.
- Must be in active treatment for AOB, and expect to have treatment completed within 24 months of enrollment into the study.
- Must have an initial cephalogram (taken prior to the beginning of treatment). A cephalogram created from a cone-beam CT scan is acceptable.

Exclusion Criteria for Patients:

- Patients with clefts or craniofacial syndromes
- Patients with non-diagnostic pre-intervention and end-of-treatment radiographs
- Patients who have significant physical, mental or medical conditions that would affect treatment compliance, cooperation, and outcome.

Pre-treatment (T1) questionnaires were completed by practitioners and patients at the enrollment visit to obtain information about practitioner characteristics, patient characteristics, pre-treatment diagnosis, and recommended/ accepted treatment. Once active treatment was complete, end-of active treatment (T2) questionnaires were completed by practitioners and their patients to obtain information about treatment methods used. All study forms can be accessed at http://nationaldentalpbrn.org/anterior-openbite-malocclusions-in-adults-recommendations-treatment-and-stability.php

Pre-treatment (T1) and post-treatment (T2) lateral cephalometric films were collected. Cephalometric images were traced using dolphin imaging software (version 11.0; Dolphin Imaging and Management Solutions, Chatsworth, Calif) and measurements were generated using an automated, custom analysis. Cephalometric landmarks, summarized in Figure 1, were first identified by one examiner and reviewed by the second examiner. Disagreements in landmark identification were resolved by means of consensus between the examiners.

A standard millimetric ruler in the cephalostat was used to calibrate millimetric measurements. When a ruler was not present, an estimate of the mesio-distal width of the lower first molar was used for calibration (N=51). To determine the molar width, twenty casts were randomly selected from archives at the University of Washington Department of Orthodontics and the mesio-distal widths were measured using digital calipers. The average width was 11.5mm, which is consistent with averages reported in orthodontic literature.[17,18] In cases where a ruler was absent in the T1 cephalogram but present in the T2 cephalogram, the estimated molar width (11.5mm) was used to calibrate the measurements at both time points. In cases where a ruler was present in

the T1 cephalogram but absent in the T2 cephalogram, the actual molar width was determined using the ruler in the T1 cephalogram and used for calibration of the T2 cephalogram.

Pre-treatment (T1) and post-treatment (T2) intraoral frontal photos were de-identified and forwarded to the research team at the University of Washington. The Photographic Openbite Severity Index (POSI) was developed to score the severity of the patient's pre-treatment openbite and final result using the pre- and post-treatment intraoral frontal photographs (Figure 2).

The seven categories listed below were developed based on the number and type of teeth with vertical overlap:

0 = All four incisor with positive 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 overlap

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

Each image was rated independently by the same two examiners, and the scores were compared. Disagreements in ratings were resolved by means of consensus between the examiners.

To calculate intra- and inter-rater reliability, ten cephalometric images and twenty intraoral frontal images were randomly selected. Cephalometric images were traced and frontal photographic images were rated by each evaluator and repeated one month later. Both inter- and intra-rater reliability were excellent as determined using intraclass correlations. For the cephalometric analysis, the mean inter-rater reliability was 97% and the mean intra-rater reliability was 98%. For the POSI, the inter-rater mean percent agreement was 92.5% and the mean kappa was 95.5%. The intra-rater mean percent agreement was 97% and the mean kappa was 98.5%.

Practitioners and patients enrolled were compensated for their participation in our study. Practitioners were compensated $100 for each study phase visit per patient completed and patients were compensated $25 for the first phase, $25 for the second phase, and $50 for the third phase.

DATA ANALYSIS

Treatment success

Treatment success was defined using the following outcomes measures:

1) Cephalometric analysis - Lateral cephalometric radiographs were used to evaluate treatment success, defined by positive overbite at the end of active treatment (T2).

2) Photographic Openbite Severity Index (POSI) - Intraoral frontal photographs were used to evaluate treatment success, defined by a score of 0 (all four incisors with positive overlap) at the end of active treatment (T2).

Success rates were calculated for the following variables to identify potential factors related to successful AOB treatment:

a) Treatment modality (ALN, FA, TADs, SX, as well as extractions)

b) Patient pre-treatment dentofacial characteristics

c) Treatment duration

d) Patient demographic characteristics

e) Practitioner demographic and practice characteristics

Treatment modality

Treatment was ascertained based on the enrollment and post-treatment questionnaires, and accounted for any changes that may have occurred during treatment. In cases where there were inconsistencies in reported treatment, clinical records were reviewed for clinical validity.

Four mutually exclusive treatment categories were identified for investigation:

1) Aligners (with no fixed appliances, TADs or orthognathic surgery)
2) Fixed appliances (with no TADs or orthognathic surgery)
3) Temporary anchorage devices (with no orthognathic surgery)
4) Orthognathic surgery

In general, the treatment groups are ordered in increasing ability to manage complex malocclusions, as well as increasing invasiveness. Patients with treatment from multiple categories were categorized into the more invasive treatment category. For example, a patient treated with both aligners and fixed appliances was placed in the fixed appliances group. Almost all patients in the TADs or orthognathic surgery groups also underwent fixed appliances. Extractions of premolar or anterior teeth were also identified and could be performed in combination with any of the treatment groups listed above. While extractions of third molars were recorded, those patients were not classified as extraction unless other teeth were extracted as part of their orthodontic treatment plan.

Patient pre-treatment dentofacial characteristics

Patient pre-treatment dental facial characteristics were reported at enrollment and cephalometric values were obtained from pre-treatment cephalograms. Dentofacial characteristics identified for examination included, profile, molar classification, maxillary and mandibular arch length, posterior cross-bite, facial pattern, and habits. Pre-treatment cephalometric values evaluated included: ANB (°), MP-SN (°), IMPA (°), and overbite (mm).

Treatment duration

Duration of active orthodontic treatment was obtained from enrollment and end of active treatment questionnaires. The dates of initial orthodontic appliance placement and appliance removal were used to calculate treatment length.

Practitioner and patient demographic characteristics

Practitioner and patient demographic characteristics were obtained from the enrollment questionnaires. Patient characteristics included age, gender, race, insurance coverage, education level, and previous orthodontic treatment. Practitioner characteristics included, specialization, country of dental school, age, gender, race and ethnicity, years in practice, geographic region of practice, and practice type.

Statistics and predictive models

Descriptive statistics were performed on the patient and practitioner sample.

Overall success rates were calculate based on the following outcome measures:

1) Positive overbite (mm) on post-treatment lateral cephalogram.
2) Post-treatment 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 incisors. Patients with a positive a cephalometric overbite may clinically lack vertical overlap of all anterior teeth, which was ascertained from intraoral frontal photographs. Because the POSI is a more discriminating measure of treatment success, all analyses were performed using the POSI index (POSI=0).

Success rates for treatment modality, patient pre-treatment dentofacial characteristics and cephalometric measures, treatment duration, patient demographic characteristics, and practitioner demographic and practice characteristics were obtained. Bivariate analyses were performed to preliminarily identify factors with statistically significant differences in treatment success.

Clustering of patients within practitioners were adjusted for by using a generalized estimating equation (GEE). This was implemented using PROC GENMOD in SAS with the CORR=EXCH option.

Multivariable predictive models were developed to identify predictors for treatment success. Specifically, the differences between success for different treatment categories (ie., SX vs. FA, TADs vs FA, ALN vs. FA) were explored. The predictive models were developed by entering all variables with $p < 0.10$. Backwards elimination was performed until all characteristics had a $p < 0.10$. Treatment category, extractions, and initial overbite (mm) were retained in the final reduced models regardless of significance level because of clinical importance. SAS software was used to perform all statistical analyses (SAS v9.4, SAS Institute Inc., Cary NC).

RESULTS

A total of 91 practitioners and 347 patients and were recruited for this study from October 2015 to June 2016. End-of-active treatment data was collected from 84 practitioners and 254 patients through December 2018. The remainder of the practitioners and patients either withdrew from the study or did not complete treatment within the study period. Patients missing T2 cephalometric data were excluded from the cephalometic analysis, leaving a total of 231 patients for cephalometic analysis. Patients missing T2 intraoral images or end of active treatment data were excluded from the POSI analysis, resulting in a total of 232 patients for POSI analysis.

The mean age of the practitioner sample was 48.8 years (SD = 9.8 years; range = 31-66 years), and 73% were male. The mean age of the patient sample was 32.1 years (SD = 11.9 years; range: 18-71 years), 75% were female, and 42% of the patients had prior orthodontic treatment. Details of practitioner and patient demographic characteristics are summarized in Tables 1 and 2.

The mean pre-treatment (T1) overbite measured from the lateral cephalograms was -2.3mm (SD = 2.1; range = -12.9 to 1.1mm). All patients did not have vertical overlap of at least one incisor (POSI >0), and no incisors had contact with opposing teeth. Sixty-five percent (N=151) exhibited no vertical overlap of all four incisors (POSI $\geq$ 4), indicating significant anterior openbites. The remaining 35% (N=81) had a pre-treatment POSI $\leq$3.

The mean post-treatment (T2) overbite measured from the lateral cephalograms was 1.4mm (SD = 1.1mm; range = -5.6 to 4.4mm). Ninety-three percent of patients (N=215) had a positive overbite measured on the post-treatment lateral cephalogram. Eighty-four percent (N=194) of

the patients exhibited positive vertical overlap of all anterior teeth at the end of treatment (POSI=0). The remaining 38 patients (16%) lacked vertical overlap of at least one incisor (POSI>0). Only six of these patients had no vertical overlap of all four incisors at the end of treatment (POSI ≥ 4). A summary of pre- and post-treatment POSI scores are presented in Table 3.

Treatment modality

The majority of patients were treated with fixed appliances (87%). Despite a recommendation rate of 37% for orthognathic surgery, only 21% of patients who completed treatment had surgery. [19] Only 8% of the patients were treated with TADs. Treatment was classified into four mutually exclusive groups, previously described, for further analysis. Eleven percent of patients were treated with aligners only, 60% with fixed appliances (no TADS or surgery), 8% with TADs (no surgery), and 21% with surgery. Treatment is summarized in Table 4.

From the descriptive analyses, there was an 81% success rate for patients treated with aligners only or with fixed appliances (no TADs or surgery). Patients in the TADs and surgery treatment groups had slightly higher success rates, at 89% and 91% respectively. These differences between all treatment groups did not reach statistical significance due to the small numbers of patients in the TADs and aligner groups (Table 5). However, orthognathic surgery was found to be a significant factor relating to increased treatment success in the predictive model comparing surgery and fixed appliances treatment groups.

Extractions

Nineteen percent of patients had extractions of anterior or premolar teeth for orthodontic treatment. Although non-extraction patients had a 10% greater success than those treated with extractions (86% vs. 76%), this difference did not reach statistical significance. Extractions were most common in the fixed appliances treatment group. Of the patients treated with fixed appliances, there was a 73% success rate for those who received extractions, and 84% for those who did not receive extractions. No patients treated with aligners had extractions. Only three patients treated with TADs and five patients treated with surgery had extractions. Extraction treatment results are summarized in tables 4 and 5.

Patient pre-treatment dentofacial characteristics

Pre-treatment dentofacial characteristics were evaluated for differences in treatment success. The results are summarized in table 6. Initial arch length was the only characteristic with significance in the bivariate analysis. Success rates were lower in patients with greater crowding. 90-91% of patients with no to mild crowding successfully finished with positive vertical overlap of all anterior teeth. Only 73-74% of those with moderate to severe crowding had complete closure of their openbite.

Patient pre-treatment cephalometric values were evaluated for differences in rates of treatment success. In the descriptive analyses, higher degrees of mandibular incisor proclination were associated with lower treatment success. Ninety-two percent of patients with IMPA $\leq 90°$ had successful treatment, compared to 76% in patients with IMPA $>90°$.

An inverse relationship between pre-treatment mandibular plane angle (MP-SN) and treatment success was also observed. Lower angle patients (SN-MP ≤30°) had greater treatment success at 96%, than patients with higher mandibular plane angles. This relationship, however, did not remain significant in any of the multivariate predictive models for treatment success.

There was no difference in success rates with magnitude of pre-treatment overbite when evaluated as both categorical and continuous variables. Success rates ranged from 81% to 85%. Patients with severe (OB <-4mm) and mild (OB > 0mm) pre-treatment openbites measured on the lateral cephalogram had equivalent success rates of 84%.

Treatment duration

The mean treatment duration was 24.8 months (SD = 11.3 months; range = 1-72 months). There was no significant difference in treatment times between treatment groups. Success rates were higher in patients with shorter treatment duration. Patients with treatment durations <30 months were 17% more successful than those with treatment >30 months (70% vs. 87%).

Patient demographic characteristics

Patient demographic characteristics, including gender, age, race, type of insurance coverage, education level, and history of prior orthodontic treatment, did not have a significant effect on treatment success (Table 7).

Practitioner demographic and practice characteristics

Practitioner characteristics were examined for differences in treatment success. There were no significant differences in practitioner's country of training, gender, race, age years out of dental school, and region of practice. Practice type was the only variable with significant differences in treatment success (Table 8). Patients treated by practitioners in an academic setting had the highest success rate (98%), while those treated in preferred provider practice settings had the lowest success rate (69%). The success rate for an academic practice setting was 18% greater than for non-academic settings (OR=10.5; P=0.005). Forty-two of the 43 patients treated in an academic setting had successful closures of their openbite. The one unsuccessful patient was treated with TADs (Table 9). It is important to note the greater percentage of patients treated with surgery and TADs in an academic setting comparted to other practice settings.

Predictive models

Multivariate models were developed to predict treatment success. Three separate models were developed to compare treatment groups (surgery vs. fixed, TADs vs. fixed, fixed vs. aligners). The results from these predictive models are summarized in Table 10.

A priori, three variables, treatment category, extractions, and initial overbite (mm) were planned for inclusion in the final reduced model, regardless of significance because of clinical importance. Other variables were included if they retained statistical significance ($P<0.10$). Academic practice setting was not included in the final model due the small number of patients treated in an academic setting with unsuccessful treatment results (N=1). However, it should be

stressed again that treatment at academic centers was associated with higher success rates than other practice settings.

Surgery vs. fixed appliances (no TADs, surgery)

The predictive model for surgery and fixed appliances treatment groups had three significant factors with a $P<0.10$. Patients treated with surgery have a 2.5 times greater chance of success than those treated with fixed appliances and no TADs or surgery (OR=2.5; P=0.07). Additionally, patients with no to mild pre-treatment crowding also had higher levels of success than those with moderate to severe crowding (OR=2.2; P=0.08). Pre-treatment mandibular incisor angulation was the most significant predictor of success with pre-treatment IMPA ≤90° having 3.5 times greater chance at success (OR=3.5; P=0.009).

TADs vs. fixed appliances (no TADs, surgery)

For patients in the TADs and fixed appliances treatment groups, treatment modality did not have a significant effect on success. There was no significant difference in success between the two treatment groups. The only significant predictor was pre-treatment mandibular incisor angulation. Patients with a pre-treatment IMPA ≤90° had a 5.9 times greater chance of success than patients with greater degrees of mandibular incisor proclination (OR=5.9; P=0.002).

Fixed appliances (no TADs, surgery) vs. aligners only

The predictive model for treatment success for patients in fixed appliances and aligners treatment groups, had three significant variables. Pre-treatment arch length was a significant predictor, with patients having no to mild crowding exhibiting a 2.5 greater odds of success than those with

moderate to severe crowding (OR=2.5; P=0.06). Once again, patients with lower degrees of pre-treatment mandibular incisor proclination (IMPA ≤90°) were more likely to have successful treatment than those with higher degrees of pre-treatment proclination (IMPA>90°) (OR=3.0; P=0.02). Finally, patients with shorter treatment durations (< 30 months) were 2.8 times more likely to have a successful treatment result than those with longer treatment times (OR = 2.8; P=0.04).

DISCUSSION

This study evaluates the treatment success of adult AOB patients treated in the United States, and shows very high success rates for orthodontically treated adult AOB patients. At the end of active treatment, 84% of the patient sample had positive vertical overlap of all four incisors, and 93% had positive overbite as measured using the central incisors on the post-treatment lateral cephalogram. Given the complexity and challenges commonly associated with treatment of AOB patients, these success rates are encouraging. However, experienced practitioners know the challenge will be the successful retention of these treatment results in the coming years.

There are a variety of orthodontic treatment modalities used to treat AOB malocclusions, but no consensus on which methods are most successful. In our study, we explored the effect of treatment modality on treatment success. Our results showed equivalent success rates for patients treated with aligners and fixed appliances (81%). This is consistent with findings from a retrospective study by Garnett, et al., reporting no differences in the magnitude of openbite and associated cephalometric changes between patients treated with fixed appliances versus clear

aligners.[20] The success rates in patients treated with TADs (89%) and orthognathic surgery (91%) were also similar. Kuroda, et al. found similar magnitudes of overbite correction in patients treated with TADs and orthognathic surgery (6.8mm vs. 7mm).[6]

It is interesting that the success rates for the two less invasive treatments are so similar, as are the rates for the two more invasive options. The greater success in TADs and surgery might be related to the ability of these treatments to predictably change the vertical position of the molars. With TADs, intrusion of both upper and lower molars is possible, and with surgery, impaction of the posterior maxilla effectively raises the vertical position of the molars.[21,22]

In the final model, which adjusts for pre-treatment characteristics and other influencing factors, orthognathic surgery was the only treatment modality found to have a significant effect on treatment success. (The difference in success between TAD patients versus fixed appliances patients may have been significant with a larger sample of TAD patients.) Patients treated with surgery had a 2.5 greater odds of success than those treated with fixed appliances and no surgery or TADs. These findings are consistent with a systematic review published in 2011, showing slightly higher treatment success and stability for surgical treatment of AOB malocclusions. These differences, however, were not found to be statistically significant. [14]

In some cases, extractions are recommended for AOB treatment. Incisal tipping during space closure, also known as the "drawbridge effect", may aid in achieving positive overlap of anterior teeth. Our results, showed no significant difference in treatment success between patients treated with and without extractions. In fact, the absolute success rates were actually lower in extraction

patients, which was somewhat surprising. Janson, et al. showed no difference, but a similar trend, in final overbite measures for patients treated with and without extractions (1.09mm vs. 1.43 mm, respectively).[11] In our sample, extractions were typically reserved for AOB patients with severe crowding and increased mandibular incisor proclination.[19] In these cases, it is possible that the extraction spaces were primarily used to resolve crowding and reduce incisor proclination, and the "drawbridge" effect may not have been fully realized. Details of treatment mechanics and stability related to extractions will be explored in future studies.

Although patient and practitioner demographic characteristics were not significant predictors of treatment success in our sample, practitioner practice type was found to have a significant influence on treatment success. Patients treated in an academic setting (N=42) had an 18% higher rate of treatment success that those treated in other practice settings (98% vs. 80%). TADs and surgery were used more often in academic settings, which might be associated with this finding. This may also be explained by the high clinical standards that accompany teaching institutions.

The predictive models for treatment success identified three additional variables that exhibited statistically significant relationships to treatment success: pre-treatment mandibular incisor proclination, pre-treatment crowding, and treatment duration.

Patients with pre-treatment mandibular incisor proclination (IMPA) less than 90 degrees had a greater chance at treatment success than those with more proclined incisors. This was found to be a significant factor in all three models. Proclined incisors may be associated with forward

tongue posture as a result of the force placed on the lingual surfaces of the incisors.[23] Patients who have more upright incisors are less likely to have anterior tongue posturing habits that can be a major challenge to AOB treatment success and stability.[24] Another possible explanation for the effect of incisor angulation relates to their vertical position as they are tipped labially. From a geometric standpoint, lower incisors positioned at a 90 degree angle have a greater vertical height than incisors that are overly proclined. Orthodontic treatment frequently proclines incisors with leveling and resolution of crowding and may improve the vertical height and overlap of incisors with a pre-treatment IMPA less 90 degrees. In patients who start with incisors positioned greater than 90 degrees, orthodontic proclination may worsen the AOB, making it more challenging to achieve successful vertical overlap of all incisors.

Pre-treatment crowding was a significant variable in two of the three predictive models for treatment success. No to mild pre-treatment crowding was associated with higher treatment success, with odds ratios of 2.2 and 2.8 in the surgery vs fixed and aligner vs fixed groups respectively. This relationship can be explained by the incisor proclination that occurs with resolution of crowding, especially in patients treated without extractions or arch expansion. As previously mentioned, overbite decreases with increased incisor proclination, which may lead to lower levels of treatment success. Crowding can be resolved with extractions, which also helps to reduce incisor proclination and avoid worsening of the AOB. Although extractions were found to be significantly associated with higher degrees of pre-treatment crowding, only 31% of the patients in our sample with moderate to severe arch length deficiencies received premolar or anterior tooth extractions.

Treatment duration was also found to be a significant predictor of success in patients treated with fixed appliances and patients treated with aligners. Patients with treatment less than 30 months had a 3.5 greater odds of treatment success. This is consistent with the relationship between treatment complexity and duration frequently observed. More complex treatments often require more time and yield less predictable results, which may explain this finding. It is important to consider that shorter treatment duration may also be associated with other factors, such as patient compliance, oral habits, and practitioner proficiency. None of these were controlled for in this study. Interestingly, this relationship was not observed in the models comparing TADs or surgery to fixed appliances. This may be explained by greater predictability and success rates of TAD and surgery treatments observed in our study. These treatment modalities also do not rely on compliance as much as clear aligner therapy does, which is a large contributing factor to length of treatment.

Interestingly, initial openbite severity, classified by pre-treatment cephalometric overbite, was not a statistically significant predictor of treatment success in any of the final models. AOBs of greater magnitude are considered more challenging malocclusions to treat, and are often thought of being associated with lower success rates. Although not statistically significant, the direction of the relationship between treatment success and pre-treatment overbite, measured on the cephalograms and openbite severity using the POSI scores, is consistent with expectations – more severe openbites were associated with less treatment success. The fact that pre-treatment openbite does not significantly influence success may be a reflection of a high level of skill and competency among the practitioners in our sample. It will be interesting to follow-up with this

in the retention stage of the study to see if magnitude of pre-treatment overbite plays a role in treatment stability.

In a prior paper, 80% of orthodontists reported using aligners occasionally or often, and the rate was 74% for miniscrew TADs.[3] However, only 11% of our sample used aligners only, and only 8% of the patients used TADs. Additionally, the expected use of aligners in less severe patients and TADs in more severe patients was not observed. These findings may indicate that practitioners are still exploring the best indications and limits for these treatment modalities. On the other hand, surgery was recommended as a first option to 37% of the patients, with an acceptance rate of 61%. This resulted in 23% of the patients planning to undergo orthognathic procedures. A few patients ultimately opted out of surgery, as our final surgical rate was 21%.

LIMITATIONS

There were several limitations of our study. The patient and practitioner sample was not randomly selected, which could lead to selection bias. The practitioners were recruited from the National Dental PBRN and their participation was voluntary. However, other than a greater number of practitioners in an academic setting, the sample was similar to the AAO membership. Practitioners were asked to enroll all patients who met the study's inclusion criteria to minimize patient selection bias. It is possible that the very high success rate we encountered is related to recruiting practitioners with a high level of interest and/or skill with respect to AOB treatment. It is also possible that having doctors and patients participating in a study led to greater levels of attention and compliance, respectively, which may have influence success rates positively.

Another limitation was treatment was not randomized. Practitioners selected the method of treatment for each patient. This resulted in an uneven distribution of patients in treatment groups as well as a clustering effect with treatment and proficiency biases. The treatment group sample sizes varied significantly. The small numbers of patients in the aligners (N=29) and TAD (N=20) groups reduced the power of our results and limited associations that could be model in the final analyses. Also, practitioners were allowed to change treatment plans during treatment, if they felt it was indicated. This might also have led to our high success rates, as patients not responding well to the original treatment could have additional treatments recommended.

The treatment timeline constraints may have resulted in a biased patient sample consisting of fewer unsuccessfully treated patients. End of active treatment data was not received from 93 subjects who either withdrew from the study, did not complete treatment in the study period or data was not provided by the practitioner. These patients may have been more difficult cases with lower chances of success. To control for this, baseline characteristics of patients with end-of-active treatment data (N= 254) and patients missing end of active treatment data (N=93) were compared. There was no difference in mean pre-treatment overbite or recommended treatment modality. Although not statistically significant, there was a trend of higher POSI scores for patients missing end-of-active-treatment data. There was a significant difference in the estimated treatment time, with patients with complete data having shorter estimated treatment times (Appendix, Table 1).

CONCLUSIONS

Overall success rates were very high for adult patients receiving orthodontic treatment for anterior openbite malocclusions. While there was a range of success for the major treatment modalities, orthognathic surgery was the only treatment group exhibiting a statistically significant influence on success rates. There were no statistically significant associations between patient demographics, or practitioner demographics and treatment success. Several pre-treatment dentofacial characteristics, including pre-treatment lower incisor proclination and level of crowding, academic practice setting, and treatment duration were significant predictors of treatment success in adult anterior openbite patients.

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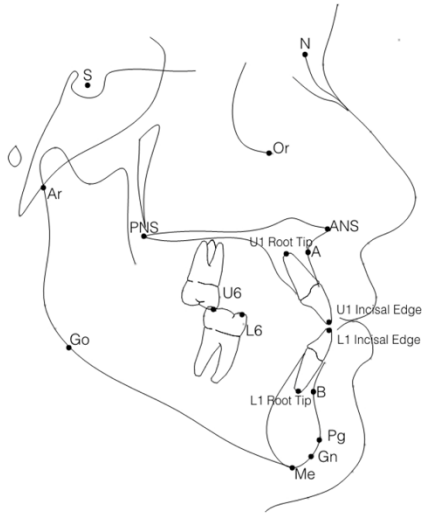

Figure 1. Cephalometric landmarks identified on pre- and post-treatment lateral cephalograms: sella (S), nasion (N), anterior nasal spine (ANS), posterior nasal spine (PNS), pogonion (Pg), gnathion (Gn), menton (Me), anatomic gonion (Go), articulare (Ar), A-point (A), B-point (B), incisal edge of the maxillary incisor (U1 incisal edge), root tip of the maxillary incisor (U1 root tip), incisal edge of the mandibular incisor (L1 incisal edge), root tip of the mandibular incisor (L1 root tip), mesiobuccal cusp tip of the maxillary first molar (U6), mesiobuccal cusp tip of the mandibular first molar (L6).

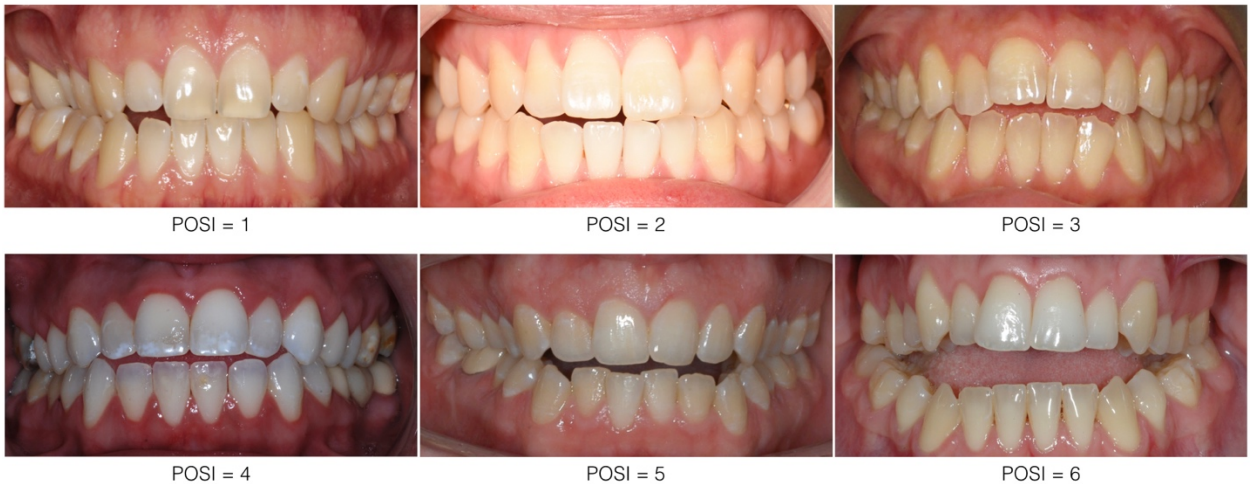

Figure 2. Photographic Openbite Severity Index (POSI)

Table 1. Practitioner demographics

	N	%
Status		
Orthodontist	82	98%
General practitioner	2	2%
Gender		
Male	61	73%
Female	23	27%
Age, years		
< 45	32	38%
45 - 54	24	29%
55 - 64	23	27%
≥ 65	5	6%
Race and ethnicity (N = 83)		
White/Caucasian	52	63%
Asian	19	23%
Multirace	2	2%
Hispanic	10	12%
Geographic region of practice		
West	34	41%
Midwest	8	10%
Southwest	16	19%
South Central	6	7%
South Atlantic	9	11%
Northeast	11	13%

* N = 84, unless indicated otherwise

Table 2. Patient demographics

	N	%
Gender (N = 253)		
Male	64	25%
Female	189	75%
Age, years (N = 253)		
18 - 20	43	17%
21 - 30	106	42%
31 - 40	58	23%
≥ 41	46	18%
Race and ethnicity (N = 253)		
White/Caucasian	146	58%
Black/African-American	23	9%
Asian	24	9%
Multirace	8	3%
Hispanic	52	21%
Previous orthodontic treatment (N = 253)		
Yes	106	42%
No	147	58%
Insurance coverage		
No dental or medical insurance	54	21%
Dental insurance does not cover orthodontics	64	25%
Dental insurance covers orthodontics	74	29%
Insurance covers orthognathic surgery	62	24%
Highest level of education (N = 253)		
High school graduate or less	45	18%
Some college or associate degree	79	31%
Bachelor degree	84	33%
Graduate degree	45	18%

* N = 254, unless indicated otherwise

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

POSI at T1	# of patients	**POSI at T2**						
		0	**1**	**2**	**3**	**4**	**5**	**6**
1	35	33	2	0	0	0	0	0
2	34	27	7	0	0	0	0	0
3	12	9	1	0	1	1	0	0
4	85	70	11	2	1	1	0	0
5	13	9	4	0	0	0	0	0
6	53	46	2	1	0	0	2	2
total	232	194	27	3	2	2	2	2

Frequency Missing = 22

Table 4. Treatment summary

Treatment	N	%
Clear aligners	50	20%
Fixed appliances	220	87%
TADs	20	8%
Surgery	53	21%
Extractions	49	19%

			Extractions	
Final Treatment Category	N	%	No	Yes
Aligners only	29	11%	29	0
Fixed (no TADs or surgery)	152	60%	111	41
TADs (no surgery)	20	8%	17	3
Surgery	53	21%	48	5

Table 5. Treatment modality and extractions vs. treatment success

	ALL	POSI = 0			Extractions	POSI = 0		No Extraction	POSI = 0	
	N=232	N=194	%	P	N=45	N=34	%	N=187	N=160	%
Final Treatment Category				0.3						
Aligners only	26	21	81%		0	0	NE	26	21	81%
Fixed, no TADs or surgery	141	114	81%		37	27	73%	104	87	84%
TADs, no surgery	19	17	89%		3	2	67%%	16	15	94%
Surgery	45	42	91%		5	5	100%	41	37	90%
missing n=23										
Extractions				0.2						
No	187	160	86%							
Yes	45	34	76%							
				OR=0.5						

[1] Percents are "row" %s, namely, the proportion of the "outcome" treatment (column heading) for that treatment comparison.
[2] P-values are adjusted for clustering of patients within practitioners using generalized estimating equations
[3] NE: Not estimable

Table 6. Patient pre-treatment dentofacial characteristics and cephalometric values vs. treatment success.

	ALL	POSI = 0		
Patient dentofacial characteristics	N=232	N=194	%	P
Profile				0.4
Convex	120	96	80%	
Straight	92	80	87%	
Concave	20	18	90%	
Molar class				0.4
I: Half or full cusp	102	89	87%	
II: Half or full cusp	71	55	77%	
III: Half or full cusp	58	49	84%	
Arch length				0.038
No crowding	44	40	91%	
Mild crowding (1-3mm)	94	85	90%	
Moderate crowding (4-6mm)	71	52	73%	
Severe crowding (>6mm)	23	17	74%	
Posterior crossbite				0.8
None	137	116	85%	
Unilateral	46	37	80%	
Bilateral	49	41	84%	
Facial pattern				0.5
High angle	127	109	86%	
Normal	93	74	80%	
Low angle	11	10	91%	
AOB Severity index (POSI)				0.6
1-3	81	69	85%	
4-6	151	125	83%	
Cephalometric values				
ANB (deg)				0.3
<0	31	28	90%	
0 - 4	111	95	86%	
>4	84	65	77%	
missing n=29				
Mandibular plane angle (MPSN, deg)				0.07
<=30 deg	24	23	96%	
>30 - 34 deg	37	32	86%	
>34 - 38 deg	50	41	82%	
>38 deg	114	91	80%	
missing n=30				
Overbite (mm)				0.9
<= -4	32	27	84%	
> -4 to -2	84	68	81%	
> -2 to 0	92	78	85%	
>0	19	16	84%	
continuous			OR = 1.10	0.3
missing n=24				
Mandibular incisor angulation (IMPA, deg)				0.05
<=86	61	55	90%	
>86 - 90	52	49	94%	
>90 - 94	43	32	74%	
>94 - 98	34	28	82%	
>98	41	30	73%	
missing n=24				

[1]Percents are "row" %s, namely, the proportion of the "outcome" treatment (column heading) for that treatment comparison.
[2] P-values are adjusted for clustering of patients within practitioners using generalized estimating equations
[3] NE: Not estimable

Table 7. Patient demographic characteristics vs. treatment success

	ALL	POSI = 0		
Patient demographics	N=232	N=194	Row %	P
Gender				0.9
Male	57	48	84%	
Female	174	145	83%	
Age, years				0.12
18 - 20	38	29	76%	
21 - 30	94	85	90%	
31 - 40	57	48	84%	
≥ 41	42	31	74%	
Race and ethnicity				0.9
White/Caucasian	137	114	83%	
Black/African-American	18	16	89%	
Asian	22	19	86%	
Multirace, other	8	6	75%	
Hispanic	46	38	83%	
Insurance coverage				0.7
No dental or medical insurance	50	43	86%	
Dental insurance does not cover orthodontics	58	49	84%	
Dental insurance covers orthodontics	68	53	78%	
Insurance covers orthognathic surgery	56	49	87%	
Education level				0.9
High school graduate or less	40	33	82%	
Some college or associate degree	74	60	81%	
Bachelor degree	77	66	86%	
Graduate degree	40	34	85%	
Previous orthodontic treatment				0.15
No	136	118	87%	
Yes	95	75	79%	

[1]Percents are "row" %s, namely, the proportion of the "outcome" treatment (column heading) for that treatment comparison.
[2] P-values are adjusted for clustering of patients within practitioners using generalized estimating equations
[3] NE: Not estimable

Table 8. Practitioner demographic and practice characteristics vs. treatment success

Practitioner characteristics	ALL N=232	POSI = 0 N=194	Row %	P
Country trained in				0.6
United States	189	157	83%	
Other	43	37	86%	
Gender				0.5
Male	172	145	84%	
Female	60	49	82%	
Race and ethniciity				0.6
White/Caucasian	141	120	85%	
Asian	64	59	83%	
Hispanic	22	19	86%	
Other/unknown	5	2	40%	
Age, years				0.6
< 45	92	74	80%	
45 - 54	55	49	89%	
55 - 64	71	60	84%	
≥ 65	14	11	79%	
Years since dental degree, years				0.5
< 10	20	18	90%	
10 - 19	91	73	80%	
20 - 29	61	54	88%	
≥ 30	59	49	83%	
Type of practice				0.05
Solo, private practice	104	86	83%	
Owner, non-solo private practice	48	39	81%	
Associate/employee private practice	23	17	74%	
Preferred provider practice	13	9	69%	
Academic	43	42	98%	
Geographic Region of Practice				NE
West	116	94	81%	
Midwest	24	22	92%	
Southwest	26	22	85%	
South Central	5	5	100%	
South Atlantic	29	27	93%	
Northeast	32	24	75%	

[1] Percents are "row" %s, namely, the proportion of the "outcome" treatment (column heading) for that treatment comparison.
[2] P-values are adjusted for clustering of patients within practitioners using generalized estimating equations
[3] NE: Not estimable

Table 9. Academic and non-academic practice settings vs. treatment success

	ALL	POSI = 0			
Academic practice	N=231	N=193	%	P	OR = 10.5
Yes	43	42	98%	0.005	
No	188	151	80%		

Primary treatment rendered

Academic practices	N = 43	N = 42	%	P
Aligners only	4	4	100%	NE
Fixed, no TADs or surgery	17	17	100%	
TADs, no surgery	9	8	89%	
Surgery	13	13	100%	

Non-academic practices	N = 188	N = 151	%	P
Aligners only	22	17	77%	0.4
Fixed, no TADs or surgery	123	96	78%	
TADs, no surgery	10	9	90%	
Surgery	33	29	87%	

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

[2] P-values are adjusted for clustering of patients within practitioners using generalized estimating equations

[3] NE: Not estimable

Table 10. Multivariable predictive models for treatment success (pairwise comparisons)

Surgery vs Fixed

	OR	P
FULL		
Tx Surgery vs fixed	2.5	0.097
Extract	0.8	0.6
No/mild crowding	2.2	0.10
Tx duration <30 months	1.7	0.3
MPSN (Base: <34)	2.2	0.2
IMPA (Base: <= 90)	3.7	0.009
OB(mm) (Base: continuous)	1.14	0.2
REDUCED		
Tx Surgery vs Fixed	2.5	0.07
Extract	0.7	0.5
No/mild crowding	2.2	0.08
IMPA (Base: <= 90)	3.5	0.009
OB(mm) (Base: continuous)	1.19	0.12

TADs vs Fixed

	OR	P
FULL		
TADs vs fixed	1.2	0.8
Extract	0.6	0.4
No/mild crowding	2.0	0.2
Tx duration <30 months	1.9	0.2
MPSN (Base: <34)	2.4	0.2
IMPA (Base: <= 90)	5.9	0.001
OB(mm) (Base: continuous)	1.14	0.2
REDUCED		
TADs vs fixed	1.1	0.9
Extract	0.4	0.2
IMPA (Base: <= 90)	5.9	0.002
OB(mm) (Base: continuous)	1.19	0.2

Fixed vs Aligners

	OR	P
FULL		
Fixed vs aligners	1.2	0.7
Extract	0.8	0.7
No/mild crowding	2.4	0.08
Tx duration <30 months	3.0	0.03
MPSN (Base: <34)	2.6	0.14
IMPA (Base: <= 90)	3.5	0.01
OB(mm) (Base: continuous)	1.11	0.4
REDUCED		
Fixed vs aligners	1.3	0.7
Extract	0.8	0.6
No/mild crowding	2.5	0.06
Tx duration <30 months	2.8	0.04
IMPA (Base: <= 90)	3.0	0.02
OB(mm) (Base: continuous)	1.15	0.2

Appendix, Table 1. Baseline characteristics, enrollment vs. end-of-active treatment patient samples

	All		Have EAT			
Baseline			No	Yes		
Charcteristics	N	%	N	N	%	P
Estimated time left						<0.001
<=6 mnths	82	24%	3	79	96%	
7-12 mnths	91	26%	21	70	77%	
12-18 mnths	87	25%	29	58	67%	
19-24 mnths	87	25%	40	47	54%	
Recommended treatmment						0.4
Aligners only	35	10%	9	26	74%	
Fixed, no TADs, surgery	146	42%	33	113	77%	
TADs, no surgery	35	10%	10	25	71%	
Surgery	129	37%	40	89	69%	
POSI Score						0.004
1	52	15%	11	41	79%	
2	39	11%	5	34	87%	
3	22	6%	9	13	59%	
4	122	35%	29	93	76%	
5	28	8%	11	17	61%	
6	84	24%	28	56	67%	
POSI Score						0.052
1-3	113	33%	25	88	78%	
4-6	234	67%	68	166	71%	
OB (mm)						no difference
Mean			-2.68	-2.35		
SD			2.2	2.1		
Min			-13.4	-12.9		
max			1.7	1.1		