Does Planned Molar Intrusion with Aligners Assist with Closure of Anterior Openbite?

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A thesis

submitted in partial fulfillment of the

requirements for the degree of

Master of Science in Dentistry

University of Washington

2022

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Program Authorized to Offer Degree:

Orthodontics

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Abstract

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Introduction: Anterior openbite (AOB) treatment is commonly regarded as a challenging malocclusion to treat and retain long-term. Aligners have become an increasingly popular AOB treatment modality due to the theory that they exert a "bite-block" effect on molars, thus helping with AOB correction. In addition, practitioners can specifically plan intrusive molar movements and use virtual posterior bite blocks on the occlusal surfaces of molars, which some believe augment the intrusion. However, we do not know whether prescribed molar intrusion, with or without bite blocks, results in actual molar intrusion and whether these features assist with AOB closure.

Methods: 42 AOB patients were recruited from 5 private practices and from the University of Washington Graduate Orthodontics Clinic. All patients were treated with Invisalign® aligners. Patients were divided into two groups based on the presence of a virtual bite "jump" in the approved ClinCheck® software treatment simulation. Patients who were prescribed molar

intrusion, with or without accompanying incisor extrusion, had a virtual bite "jump" at the last stage of the simulated treatment, and were assigned to the planned molar intrusion (PMI) treatment group. Patients without prescribed molar intrusion did not have a virtual bite "jump" and were assigned to the no planned molar intrusion treatment (No-PMI) treatment group. PMI patients were further categorized by the presence or absence of virtual posterior bite blocks on the occlusal surfaces of molars (PMI-BB and PMI-No BB, respectively). Patient and treatment characteristics were evaluated using descriptive statistics. Treatment success was determined based on positive vertical incisor overlap in post-treatment cephalograms. Treatment changes were assessed using pre- (T1) and post-treatment (T2) cephalometric radiographs (Welch Two-Sample T-Test, 95% confidence interval, $p=0.05$). Patients were invited to return to their offices at least 1-year post-treatment (T3) for an intraoral frontal photograph to assess treatment stability using the Photographic Openbite Severity Index (POSI).

Results: In the retrospective arm of the study, there were 18 No-PMI and 24 PMI patients (total N=42). The PMI treatment group had more severe pre-treatment openbites, greater pre-treatment crowding, and longer treatment times. The mean overbite change was 2.6 mm (SD=1.1) for No-PMI and 3.2 mm (SD=1.7) for PMI patients ($p=0.15$). All patients had positive vertical incisor overlap in T2 cephalograms, indicating 100% treatment success. The openbites were corrected primarily by incisor retroclination and extrusion in both treatment groups. Small amounts of molar intrusion were observed for PMI patients (0.1-0.6 mm), and reached statistical significance after controlling for potentially confounding variables ($p=0.034$). The amount of planned molar intrusion was not well correlated with the amount of measured molar intrusion, mandibular plane closure, or decrease in AFH. 15 patients from the original sample returned for T3 intraoral

frontal photographs and were included in the POSI analysis. Of those, 12 (80%) had a POSI score of 0, 2 (13.3%) had a POSI score of 1, and 1 (6.7%) had a POSI score of 4.

Conclusion: Prescribing molar intrusion for openbite patients appears to result in a small, statistically significant amount of mean molar intrusion (less than 1 mm), and may be of some assistance with openbite closure. However, the majority of the correction appears to be the result of incisor retroclination and extrusion. Patients undergoing aligner therapy exhibited a high success rate for openbite closure. Based on our limited sample, treatment stability was similar to that reported for fixed appliances; however, larger sample sizes and longer follow-up periods are necessary.

Acknowledgements

I would like thank the University of Washington Department of Orthodontics and the University of Washington Orthodontic Alumni Association for their support of my academic pursuits. In addition, I am grateful to Align Technology® for the additional funding they provided for this project through the 2020 Align Technology® Research Award. Thank you to my research committee members, Drs. Greg Huang, Bobby Cohanim, Roozbeh Khosravi, and Sandra Tai for your mentorship and guidance. In addition, a sincere thank you to Lloyd Mancl for his statistical support. Thank you to my brother, Dr. Samuel Finkleman, for help with cephalometric landmark identification. Finally, I would like to express my gratitude and appreciation for my fiancé, family, and friends for their love and encouragement. Last but not least, thank you to Gus for being the best puppy.

INTRODUCTION

Anterior openbite (AOB) is defined by a lack of vertical overlap of the maxillary and mandibular incisors in maximum intercuspation.[1,2] According to the National Health and Nutrition Examination Survey (NHANES) III, approximately 3.5% of the United States population is affected by this type of malocclusion.[3] AOB is associated with significant psychological and functional concerns due to the compromised esthetics, difficulty incising food, abnormal swallowing pattern, and speech irregularities that accompany this type of malocclusion.[4] The etiology of AOB is complex and multifactorial. Vertical growth patterns, oral habits (e.g. digit-sucking, anterior tongue position), and mouth breathing are some of the etiologic factors that have been reported.[5]

Historically, AOB has been regarded as a challenging malocclusion to treat and retain long-term due to its complex etiology and propensity towards relapse. [1,6,7] Currently, there is no consensus on the optimal treatment method. Treatment options include traditional fixed appliances, vertical elastics, extractions, myofunctional therapy, clear aligner therapy, Temporary Anchorage Devices (TADs), and orthognathic surgery. For all the non-surgical methods, correction of the vertical relationship is primarily achieved through incisor extrusion, molar intrusion, or a combination of both. Theoretically, molar intrusion allows correction of AOB via mandibular auto-rotation, thereby minimizing the amount of incisor extrusion needed. Therefore, treatment modalities that correct AOB through molar intrusion may be useful for patients with adequate or excessive incisal display where extrusion of the incisors is contraindicated.

TADs and orthognathic surgery are more robust treatment modalities used to correct AOB. TADs (mini-screws and plates) have been shown to successfully treat AOB by molar intrusion through skeletal anchorage.[8,9] Surgical techniques for the correction of skeletal AOBs in skeletally mature patients include Le Fort I maxillary osteotomy, bilateral sagittal split osteotomy (BSSO), and bimaxillary osteotomies.[10-12] In Le Fort I maxillary osteotomy, impaction of the posterior maxilla effectively raises the vertical position of the molars, which allows mandibular autorotation. However, some amount of vertical relapse should be expected, regardless of the surgical technique.[12] In a large, prospective, cohort study evaluating different treatment modalities for AOB correction, orthognathic surgery was found to be the most successful technique for correcting AOB compared to non-surgical treatment modalities.[13] Importantly, some patients may not accept the options of TADs or orthognathic surgery due to their risks and costs.

Clear aligner therapy is becoming an increasingly popular treatment modality for patients with AOB.[14] Clear aligner therapy may offer several distinct advantages over traditional fixed appliances for the treatment of AOB. First, clear aligner therapy is often preferred by patients due to improved comfort and esthetics.[15] In addition, clear aligner therapy may be a superior treatment modality for AOB correction compared to fixed appliances, as the latter tends to have extrusive effects on the posterior dentition, leading to clockwise rotation of the mandible.[16,17] Lastly, some have proposed that the thickness of the plastic covering the posterior teeth exerts a "bite-block" effect when combined with masticatory forces, leading to molar intrusion and mandibular autorotation.[18,19]

Although several different clear aligner systems exist now, Invisalign® (Align Technology®, Santa Clara, California) is still regarded as one of the most popular clear aligner systems. In 2015, Align Technology launched Invisalign® G6, a software advancement that included ClinCheck Pro® and 3D Controls®.[20] This software development allowed practitioners to make changes to tooth positions in the ClinCheck® setups in real time. In addition to prescribing molar intrusion with 3D Controls®, some orthodontists utilize virtual occlusal attachments on posterior teeth to augment the proposed "bite-block" effect (Figure 1, Appendix). However, little is known about whether these planned features yield the intended results – actual molar intrusion, anterior openbite closure, and a decrease in the mandibular plane angle and anterior facial height. Furthermore, if molar intrusion is possible with clear aligners, it is unknown whether the addition of virtual bite blocks on the molars augments the molar intrusion effect.

Several case reports have demonstrated successful treatment of significant AOBs using clear aligner therapy.[18,19] However, despite its growing popularity, there is still uncertainty regarding the exact mechanism of openbite correction when using clear aligners. A retrospective study evaluating the ability of clear aligners to control the vertical dimension in both deep bite and openbite patients found that openbite correction occurred primarily by incisor extrusion.[21] However, this study had a relatively small sample size of AOB patients. A retrospective study comparing the mechanism of AOB closure for patients treated with fixed appliances and clear aligners found both treatment modalities corrected the openbite through maxillary incisor retroclination and maintenance of the vertical position of the posterior dentition.[22] In contrast, two retrospective studies concluded that molar intrusion and mandibular autorotation contribute to openbite correction.[23,24] However, both of these studies lacked a comparison group and did not

consider the effects of aligner treatment plan design on the outcomes of openbite closure, including the specific tooth movements or aligner features that were or were not programmed into the aligners. The amount of molar intrusion reported in both of these studies was less than 1 mm.

This study evaluates the effect of planned molar intrusion, with and without virtual occlusal bite blocks, on AOB correction with aligners. Treatment success and stability at long-term follow-up are also investigated.

AIMS

1) To determine whether prescribed molar intrusion results in real molar intrusion with clear aligner therapy.
2) To elucidate the mechanism of AOB correction for patients treated with and without prescribed molar intrusion, and to determine whether the presence of virtual posterior bite blocks augments the molar intrusion.
3) To compare treatment success between aligner patients treated with and without prescribed molar intrusion.
4) To assess treatment stability at least 1-year post-treatment using the POSI analysis.

METHODS

AOB patients were recruited from private practice orthodontic offices located in Vancouver, British Columbia, the Hawaiian Islands, and Seattle, Washington, as well as the University of

Washington Graduate Orthodontics Clinic. Institutional Review Board (IRB) approval was obtained from the University of Washington (STUDY00010648).

Inclusion criteria for patients:

1. Must be at least 15 years of age at the end of treatment.
2. Must have AOB malocclusion prior to treatment, defined by one or more incisors that do not have vertical overlap with teeth in the opposing arch AND lack of incisor contact on all incisors.
3. Must be treated with Invisalign® clear aligners with or without prescribed molar intrusion.
4. Must have started treatment no earlier than November 14, 2011 (when the G4 Invisalign® software update was introduced).
5. Must have completed treatment by the date of IRB approval OR be in active treatment but estimated to complete treatment by September 2021.

Exclusion criteria for patients:

1. Patients with clefts or craniofacial syndromes.
2. Patients who had fixed appliances, extractions, TADs, or orthognathic surgery as part of their treatment.
3. Patients with non-diagnostic pre- (T1) or post-treatment (T2) cephalometric radiographs.
4. Patients who have significant physical, mental, or medical conditions. Patients with these conditions were excluded because of the assumption that the presence of these conditions could affect treatment compliance and outcome with clear aligner therapy.

All efforts were made to recruit consecutively treated patients, when possible. In the retrospective arm of the study, patients were identified and screened for eligibility as follows:

1. For four of the private practices, the lead researcher was granted temporary, remote access to the office's Invisalign® software. The search term "openbite" was used to identify patients from that office who may qualify for the study.
2. One of the private practices did not grant the lead researcher temporary, remote access to the office's Invisalign® software. The orthodontist from that office performed their own data collection, de-identification, and records transmission. The search term "openbite" was used to identify patients from that office who may qualify for the study.
3. For University of Washington Graduate Orthodontics Clinic, the lead researcher had access to the clinic's Invisalign® software. The search term "openbite" was used to identify patients from the graduate clinic who may qualify for the study.

After assembling a preliminary patient list, the Invisalign® ClinCheck® software plans and electronic dental records were accessed to determine whether the patients met the inclusion criteria. For the office that did not provide temporary, remote access to the Invisalign® software, the lead researcher accessed the patients' Invisalign® ClinCheck® software plans while the orthodontist was present.

Patients were divided into two groups based on the presence of a virtual bite "jump" in the approved ClinCheck® software treatment simulation (Figure 2). Patients who were prescribed molar intrusion, with or without accompanying incisor extrusion, had a virtual bite "jump" and were assigned to the planned molar intrusion (PMI) treatment group. Patients without prescribed

molar intrusion did not have a virtual bite “jump” and were assigned to the no planned molar intrusion treatment (No-PMI) treatment group. PMI patients were further categorized by the presence or absence of virtual posterior bite blocks on the occlusal surfaces of molars (PMI-BB and PMI-No BB, respectively). T1 and T2 cephalograms of representative patients from each treatment category can be found in Figure 3.

Tooth movement tables from the ClinCheck® software plans were used to record the amount and direction of the planned molar movements across all accepted ClinCheck® software plans as follows:

1. For each molar, the amount and direction of planned vertical molar movements was recorded. Positive numbers indicated extrusion and negative numbers indicated intrusion.
2. The sum of the molar movements was taken for each molar across all accepted ClinCheck® software plans.
3. Next, the amount of planned extrusion or intrusion for “pairs” of teeth was calculated by adding the vertical molar movements for opposing pairs of teeth. For example, if the upper right second molar had a total of 1 mm of vertical intrusion and the lower right second molar had 0.5 mm of vertical intrusion, the total intrusion for the pair was 1.5 mm. The right and left 1st molar pairs were averaged, as were the right and left 2nd molar pairs.

All records were de-identified prior to assessment and each patient was assigned a unique ID. A key that linked the patients to their unique IDs was kept by the lead investigator, but was not accessed during the data analysis portion of the study.

Occlusal views of T1 maxillary and mandibular scans were used to assess arch length. Arch length deficiency (ALD) and arch length excess (ALE) at T1 were rated independently by two examiners (SF, GH), and the scores were compared. Positive numbers represented ALE and negative numbers represented ALD. Disagreements in ratings were resolved by means of consensus between the examiners. If both arches had crowding or one arch had crowding and the other arch had spacing, the most crowded arch was reported. When both arches had spacing, the least spaced arch was reported.

T1 and T2 lateral cephalograms 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 4, were first identified by one examiner (SF) and reviewed by the second examiner (SAF). Disagreements were resolved by means of consensus. If consensus could not be reached, a third examiner was the tie-breaker (GH). Figures 5-9 summarize the cephalometric reference planes, molar vertical position measurements, incisor vertical position measurements, incisor angulation measurements, and skeletal measurements used in the cephalometric analysis.

Whenever possible, the mesial cusp tip of each molar was selected. If there were problems identifying the mesial cusp tip in one or both cephalograms, a different landmark was agreed upon by the two examiners (SF, SAF) and then identified in T1 and T2 cephalograms. Alternative landmarks included distal cusp tips, the intersection of a restoration and tooth

surface, or other anatomical features that could be identified in both cephalograms. For this reason, no comparisons of absolute molar vertical positions were performed, only comparisons of the differences between molar vertical positions at the T1 and T2 times.

A standard millimetric ruler in the cephalostat was used to calibrate linear measurements. In cases where the ruler was absent from one or both timepoints, one of two methods were employed:

1. A reproducible measurement from the nosepiece of a cephalogram taken using the same cephalostat was used to calibrate the cephalogram with the missing ruler. The largest reproducible distance on the nosepiece was used for calibration.
2. An alternative anatomic structure was used for calibration. In general, the anatomic structure used was the largest and clearest midline structure (for example, sella-nasion).

For these patients, a superimposition was performed to ensure that the magnification adjustments were accurate.

Intra- and inter-rater reliability were assessed by randomly selecting 10 cephalometric images. Cephalometric images were independently traced by two evaluators (SF, SAF) and repeated three weeks later. *A priori*, nine key measures were selected based on their clinical importance to determine intra- and inter-rater reliability. These measures were mandibular plane angle (MP-SN) (deg), anterior facial height (AFH) (mm), U1-NA (deg), L1-NB (deg), overbite (mm), U6-PP (mm), L6-MP (mm), U1-PP (mm), L1-MP (mm).

In the prospective arm of the study, patients were invited to return to their office at least 1 year (T3) after the completion of treatment for an intraoral frontal photograph. Only patients who were 18 years or older at the time of recall were asked to participate in the prospective arm of the study. The Photographic Openbite Severity Index (POSI) was used to score the severity of the patient's final result (Figure 10).[25] 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 1st premolar without vertical overlap

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

Private practice offices were compensated for their participation in the retrospective and prospective arms of the study. Private practices received a $50 Amazon gift card for each patient

enrolled in the retrospective arm of the study. In addition, private practices received a $50 Amazon gift card for each patient successfully recruited to the prospective arm of the study. Patients were compensated with a $50 Amazon gift card for their participation in the prospective arm of the study, and they received a complimentary retainer check.

Data Analysis

The sample size was determined based on the primary outcome measure, which was change in vertical molar position. The researchers decided *a priori* that a 1.5 mm difference in vertical molar position would be clinically meaningful. It was determined that a sample size of 17 patients per group would be needed for demonstrating a 1.5 mm difference (SD = 1.5) with 80% power based on a two-sample t-test using two-sided 0.05 significance level.

Descriptive statistics, including mean, standard, median and interquartile range for quantitative measures and number and frequency for categorical measures, were calculated for the patient and treatment characteristics, as well as for office demographics. Characteristics and demographics were compared between treatment groups using a two sample t-test for quantitative variables and a chi-square test or Fisher's exact test for categorical variables.

Treatment success was defined as having a positive overbite measurement at the end of active treatment in the T2 cephalogram. Treatment stability was based on all four incisors having positive vertical overlap in the T3 intraoral frontal photograph (POSI Score = 0).

Cephalometric measurement averages were compared between PMI and No-PMI treatment groups at T1 using a (Welch's) two-sample t-test and 95% confidence interval (CI) for the difference between group averages. Average cephalometric treatment changes between PMI and No-PMI groups were compared using a two-sample t-test and 95% confidence interval for the difference in the average changes. The same tests were applied to PMI-BB and PMI-No BB subgroups.

The relationships between prescribed molar intrusion and measured molar intrusion, MP-SN change, and AFH change were assessed. Prescribed molar movements (mm) obtained from the ClinCheck® were averaged across all 4 molar pairs for a given subject. Measured molar movements (mm) obtained from the cephalometric analysis were averaged across all molars for a given subject (U7-PP, U6-PP, L7-MP, and L6-MP). MP-SN and AFH change were obtained from the cephalometric treatment changes analysis.

Linear regression analysis was used assess the influence of treatment type (PMI or No-PMI) on measured molar intrusion, controlling for the following variables: overbite (mm), MP-SN (deg), crowding (mm), age, and gender at T1. A p-value <0.05 was used to determined statistical significance. All analyses were done using R, Version 4.0.0.

RESULTS

Eight cephalograms had missing rulers requiring alternative methods of calibration. One cephalogram was calibrated using the sella-nasion distance (mm) of the later timepoint. Seven cephalograms were calibrated using reproducible measurements from nosepieces of the same

cephalostat. Alternative, non-mesiobuccal cusp tip landmarks were used for at least one molar in 18 patients.

Both the intra- and inter-rater cephalometric landmark reliability were excellent, as determined by using interclass correlations. The mean intra-rater reliability was 0.98 and 0.99 for the two evaluators (SF, SAF) and the mean inter-rater reliability was 0.98.

<u>Patient and office characteristics</u>

After applying the inclusion and exclusion criteria, a total of 42 patients were included in the retrospective portion of the study. The mean age of the patient sample was 30.2 years (SD=11.9 years; range=13.2-63.4 years), 23 (54.8%) were female, and 19 (45.2 %) were male. In the overall sample, 29 (69.0%) of patients had crowding, 10 (23.8%) had adequate arch length, and 3 (7.1%) had spacing. There were significant differences in the amount of crowding and spacing between treatment groups (p=0.015). Significantly more PMI patients had pre-treatment crowding compared to No-PMI patients (Table 3). A summary of the patient demographics can be found in Table 1.

A total of 6 orthodontic offices participated in the study. 5 of the orthodontic offices were private practices in Seattle, Washington, the Hawaiian Islands, and Vancouver, British Columbia. Patients were also recruited from the University of Washington Orthodontics Graduate Clinic. Clinics were asked to recruit eligible patients consecutively, however, the number of patients recruited from each office was not evenly distributed, nor were the treatment approaches. (Table 2). In particular, some providers showed a clear preference for No-PMI (Office B) or PMI

(Office A, C, D). In addition, only one provider used virtual posterior bite blocks for PMI patients (Office C).

Treatment characteristics

There were 18 (42.9%) No-PMI and 24 (57.1%) PMI patients (total N=42). Of the 24 PMI patients, 7 (29.2%) were treated with the incorporation of virtual posterior bite blocks on the occlusal surfaces of the molars (PMI-BB). The other 17 (70.8%) were treated without the addition of virtual posterior bite blocks (PMI-No BB). All 24 PMI patients also had some amount of planned incisor extrusion.

The mean treatment time for the overall sample was 22.8 months (SD=12.6 months; range=5.5-68.9 months). The mean treatment time for No-PMI and PMI treatment groups was 18.5 months (SD=9.6 months) and 26.1 months (SD=13.8 months), respectively, and the difference was statistically significant ($p=0.042$) (Table 1).

The mean amount of molar movement prescribed in the treatment simulations was significantly different for No-PMI and PMI treatment groups ($p<0.001$). PMI patients had a mean of 2.4 mm of prescribed molar intrusion across all 4 pairs of molars, while No-PMI patients had a mean of 0.2 mm of prescribed molar extrusion. The maximum amount of prescribed molar intrusion across all accepted ClinCheck® software plans was on average 1 mm greater than the mean (Table 4, Figure 11). The amount of prescribed molar movement was also compared between PMI-BB and PMI-No BB treatment groups. The mean amount of prescribed molar intrusion was

significantly greater for PMI-BB (-4.4 mm; SD=1.4) patients compared to PMI-No BB patients (-1.6 mm; SD=1.8) (p=0.002) (Table 5, Figure 12).

The number of sets of aligners ranged from one to seven sets. A breakdown of the number of sets of aligners by treatment type can be found in Table 6. The mean number of active aligners was significantly greater for PMI patients (74.1 aligners; SD=29.8 aligners; range=30.0-155.0, p< 0.001) (Table 7). There was good correlation between treatment time and number of sets of aligners (Spearman rank correlation coefficient=0.80) (Figure 13).

Cephalometric Analysis

T1 and T2 Summaries

At T1, overbite (mm) was significantly decreased (i.e., more severe openbite) for PMI patients (p=0.011). At T2, there were significant differences in ANB (deg), U1-NA (deg), U1-NA (mm), and overbite (mm). ANB (deg) was significantly greater for No-PMI patients compared to PMI patients (p=0.017). U1-NA (deg) and U1-NA (mm) measurements also reached statistical significance at T2, with PMI patients having greater proclination and protrusion of the upper incisors at the end of treatment (p=0.005 and p=0.002, respectively). Overbite was significantly greater at T2 for No-PMI patients compared to PMI patients (p=0.028). A summary of T1 and T2 patient characteristics for PMI and No-PMI treatment groups can be found in Table 8.

When comparing PMI-BB and PMI-No BB treatment groups, there were no differences at either timepoint for any cephalometric variable (Table 9).

Treatment Success

All patients, regardless of treatment modality, had positive vertical overlap of the incisors at T2 as measured on cephalograms, indicating 100% treatment success.

Univariate T2-T1 Treatment Changes

The mean overbite change was 2.6 mm (SD=1.1) for No-PMI and 3.2 mm (SD=1.7) for PMI patients (p=0.15). Both treatment groups had retroclination of the upper and lower incisors and the difference between groups was not statistically significant (p=0.46 and p=0.48, respectively). The mean upper incisor retroclination was -5.3 deg (SD=7.1) for No-PMI and -3.8 deg (SD=6.0) for PMI patients (p=0.046). The mean lower incisor retroclination was -2.0 deg (SD=3.9) for No-PMI and -3.1 deg (SD=6.6) for PMI patients (p=0.048). Both treatment groups had extrusion of upper and lower incisors and the differences between groups were not statistically significant (p=0.56 and p>0.99). The mean upper incisor extrusion was 1.3 mm (SD=1.3) and 1.1 mm (SD=1.3) for No-PMI and PMI patients, respectively. The mean lower incisor extrusion was 0.8 mm (SD=0.7) and 0.8 mm (SD=1.1) for No-PMI and PMI patients, respectively.

For the No-PMI group, vertical molar position remained relatively unchanged. All molars in the PMI group displayed small amounts of mean molar intrusion, from 0.1 to 0.6 mm. The difference in vertical molar position did not reach statistical significance for any of the molars in the univariate analysis. AFH decreased for PMI patients (-0.7 mm; SD = 1.5 mm) and increased slightly for No-PMI patients (0.3 mm; SD = 1.3 mm). The difference between groups was statistically significant (p=0.030). MP-SN decreased slightly for PMI patients (-0.5 deg; SD = 1.3 deg) and stayed relatively the same for No-PMI patients (0.1 deg; SD = 1.0 deg). However,

this difference did not reach statistical significance (p=0.069). A summary of T2-T1 treatment changes for PMI and No-PMI treatment groups can be found in Table 10.

PMI patients were further categorized by the presence of absence of virtual posterior bite blocks. The mean overbite change was 3.4 mm (SD=1.8) for PMI-No BB and 2.8 mm (SD=1.5) for PMI-BB patients (p=0.40). PMI-No BB patients had more upper incisor retroclination (-4.6 deg; SD = 6.5) than PMI-BB patients (-1.8 deg; SD = 4.6), but the difference was not statistically significant (p=0.25). Following a similar pattern, PMI-No BB patients had more lower incisor retroclination (-3.8 deg; SD = 7.3) than PMI-BB patients (-1.5 deg; SD = 4.2), but the difference was not statistically significant (p=0.35). Both groups had extrusion of upper and lower incisors and the difference between groups was not statistically significant (p=0.36 and p=0.72). The mean upper incisor extrusion was 1.2 mm (SD=1.3) and 0.7 mm (SD=1.3) for PMI-No BB and PMI-BB patients, respectively. The mean lower incisor extrusion was 0.9 mm (SD=1.2) and 0.7 mm (SD=0.9) for PMI-No BB and PMI-BB patients, respectively.

There was a trend of more upper molar intrusion for PMI-BB patients; however, the differences did not reach statistical significance. On average, there was -1.2 mm (SD=1.0) of intrusion of upper first molars relative to palatal plane (U6-PP) for PMI-BB patients compared to -0.3 mm (SD=0.9) of intrusion for PMI-No BB patients (p=0.085). There was -0.5 mm (SD=0.7) of intrusion of upper second molars relative to palatal plane (U7-PP) for PMI-BB patients compared to 0.1 mm (SD=1.0) of extrusion for PMI-No BB patients (p=0.094). However, the lower molars did not follow this pattern. Interestingly, there was statistically significant more intrusion of the lower first molar (L6-MP) for PMI-No BB patients (mean=-0.5 mm; SD=0.9)

compared to PMI-BB patients (mean=0.1 mm; SD=0.5) (p=0.046). The lower second molar (L7-MP) displayed similar, small amounts of intrusion for both groups, regardless of the presence or absence of posterior bite blocks (p=0.67).

AFH decreased for both PMI groups, but more so for PMI-BB patients (-0.9 mm, SD=1.4) compared to PMI-No BB patients (-0.6, SD=1.6). The difference was not statistically significant (p=0.3). Change in MP-SN followed a similar pattern, with more decrease observed for PMI-BB patients (-1.1 deg, SD=1.2) compared to PMI-No BB patients (-0.3 mm, SD=1.2). Again, the difference was not statistically significant (p=0.8). Occlusal plane-SN (deg) increased significantly for PMI-BB patients (1.3 deg, SD=1.4) compared to PMI-No BB patients (-0.3 deg, SD=1.7) (p=0.03). A summary of T2-T1 treatment changes for PMI-BB and PMI-No BB can be found in Table 11.

Importantly, the relationships between the amount of prescribed molar movement and the amount of measured molar movement, MP-SN change, and AFH change were weak and non-statistically significant (Figures 14-16).

Multivariate Regression Analysis

Based on a linear regression analysis that controlled for overbite (mm), MP-SN (deg), crowding (mm), age, and gender at T1, the average measured molar intrusion for the PMI group was 0.72 mm greater than the change for the No-PMI group and the difference was statistically significant (95% CI, 0.08 to 1.4 mm; p-value=0.034). Mean measured molar intrusion was 0.7 mm greater in females compared to males, which was statistically significant (95% CI, 0.09 to 1.3 mm; p-

value=0.032). Mean measured molar intrusion was 0.03 mm/year greater in older patients and this finding was also statistically significant (95% CI, -0.06 to -0.01 mm; p-value=0.011) (Table 12).

T3 POSI Scores

15 patients from the original sample completed T3 frontal photographs and were included in the POSI analysis. The average follow-up period for the overall sample was 28.9 months (SD=16.0; range=14.2-69.1 months). Of those patients included in the POSI analysis, 10 patients had No-PMI and 5 patients had PMI. Of those, 12 (80%) patients had a POSI score of 0, indicating stability of the AOB correction. 2 (13.3%) patients had a POSI score of 1. Only 1 (6.7%) patient had a POSI score of 4. A summary of the POSI scores by treatment type can be found in Table 12.

DISCUSSION

This study evaluates the effect of prescribed molar intrusion in AOB patients treated with aligners. Even without prescribed molar intrusion, some authors report that the thickness of the aligner material between the molars may cause some molar intrusion, which assists with AOB closure.[18,19] If molars can be intruded with aligners, then specifically prescribing molar intrusion in the ClinCheck® treatment plan, with or without posterior bite blocks on the molars, should result in more molar intrusion. It has been speculated that for every 1 mm of molar intrusion, there should be 3 mm of AOB closure as a result of autorotation of the mandibular plane, which should also cause shortening of the AFH.[26] In fact, one could argue that a dose-response relationship should exist – more planned intrusion should result in more actual intrusion and

proportionate changes in the mandibular plane and AFH. While the changes observed in molar intrusion, mandibular plane, and AFH tended to be small, they did all change in the anticipated direction.

There are some interesting trends from this study. First, the amount of molar intrusion in patients who did not specifically have planned molar intrusion was essentially zero. The lack of measured molar intrusion observed closely resembled the amounts reported in previous studies.[21,22] These studies did not report whether molar intrusion was specifically planned or not; however, it seems unlikely that these patients had planned molar intrusion.

Second, in the total group of patients with planned molar intrusion, there does appear to be a small amount of consistent mean molar intrusion, but none of the changes reached statistical significance in univariate analyses. However, the multivariate analysis did reveal a small, but statistically significant, amount of molar intrusion in the PMI group. This mean amount of molar intrusion (0.72 mm) is similar to the amounts reported in previous studies.[23,24] The skeletal changes reported in our study were similar in magnitude to those reported in one study,[23] but less than those reported in another study.[24] In contrast, Khosravi et al. and Garnett et al. showed a slight mean increase of MP-SN and AFH, which is opposite of expectations.[21,22] Again, these patients likely did not have prescribed molar intrusion. Overall, these findings suggest that no-PMI results in a maintenance of the molar vertical positions, whereas PMI may result in a small amount of actual intrusion.

The multivariate analysis also revealed significant differences based on gender and age. Specifically, female patients had 0.7 mm more mean molar intrusion, and the difference was statistically significant (p=0.032). One possible explanation is the lower bone density in females compared to males.[27] In addition, some, but not all, studies report higher compliance observed in female orthodontic patients.[28] It is possible that the female patients in our study were more cooperative than their male counterparts. Both of these factors may influence the ability to successfully intrude molars with aligners. Age had a small, but significant effect (0.03 mm/year, p=0.011). This may have an impact for patients with large age differences, but not for patients of similar ages. In our sample, the second oldest patient (58 years at the start of treatment) also happened to have one of the largest amounts of measured molar intrusion (2.25 mm), which could explain this finding in the multivariate analysis. These trends may be interesting to investigate in future studies.

Third, in both treatment groups, approximately 3 mm of openbite correction occurred and the primary mechanism was incisor extrusion and retroclination. This aligns with the results from Khosravi et al. and Garnett et al., who also concluded that openbite correction was primarily due to incisor extrusion and retroclination, as well as good vertical control. In contrast, Moshiri et al. and Harris et al. concluded that molar intrusion, as well as corresponding mandibular plane and AFH change, significantly contributed to openbite correction. However, neither of these studies had controls.

Fourth, there was a trend observed of greater upper molar intrusion for patients treated with posterior bite blocks, but this difference did not reach statistical significance. The significant

increase in occlusal plane-SN (deg) for patients with bite blocks is likely related to the observed change in upper molar position, incisor extrusion, and clockwise rotation of the occlusal plane. Interestingly, the lower first molar had statistically significant more molar intrusion in the group treated without bite blocks, which was opposite of the expected outcome. Those with bite blocks displayed more mandibular plane closure and AFH shortening, but neither reached statistical significance due to the small number of bite block subjects. Another explanation for the minimal effect of the bite blocks is that AOB patients tend to have weak musculature and spend minimal time with posterior teeth together. However, our sample of bite block patients was very small and restricted to a single provider, so it is not appropriate to generalize these findings.

PMI and No-PMI patients were different at the onset of treatment for a few reasons. First, PMI patients presented with significantly worse open bites. Second, PMI patients had more pre-treatment crowding. This is important because proclination to resolve crowding results in relative intrusion of the incisors, which makes open bite correction even more difficult. Third, treatment time and number of aligners were greater in PMI patients. All of these factors considered together likely indicate greater treatment complexity for patients who were prescribed molar intrusion, rather than a less efficient treatment approach. It is also possible to consider sub-par compliance as a rationale for greater treatment time and number of sets of aligners in these patients. However, compliance was not assessed for either treatment group.

At T2, No-PMI patients had a more Class II skeletal relationship. This relationship was also present at T1, but did not reach statistical significance until T2. The increased proclination and protrusion of the upper incisors at T2 for PMI patients can be attributed to the fact that these

patients had more crowding at T1. Therefore, there was forward movement of the upper incisors to resolve the arch length discrepancy. Mean overbite at T2 was significantly shallower for PMI patients. This is likely related to the fact that PMI patients had more severe initial openbite presentations.

In general, the patients included in the study presented with mild to moderate openbites. All patients, regardless of treatment group, had positive vertical incisor overlap at the end of treatment, indicating 100% treatment success. This finding was surprising to the researchers given the fact that AOB is known to be a challenging malocclusion to treat, and suggests that aligners are an appropriate appliance for correction of mild to moderate AOBs, irrespective of treatment design. In comparison, a study by Todoki, et al. found 81% treatment success for patients treated with aligners only.[13] However, in the aforementioned study, treatment success was determined not only based on central incisor overlap on T2 cephalograms, but also on POSI analysis of T2 intraoral frontal photographs. It is possible that some of the patients in our study had openbites on lateral incisors not measurable on 2-dimensional cephalometric radiographs, which could explain the higher rates of treatment success in our study. In addition, the patients in Todoki's study had more severe pre-treatment openbites (mean=-2.3 mm; SD=2.1; range -12.9-1.1 mm), which may also explain the higher treatment success rate in the present study.

Two patients with large amounts of planned molar intrusion had relatively large changes in molar intrusion, MP angle, and/or anterior facial height. One of these subjects had 6.2 mm of prescribed molar intrusion and 3.3 mm of measured molar intrusion. This subject also had a significant reduction in MP-SN and AFH (2.3 deg and 3.7 mm, respectively). On inspection of

the subject's records, the quality of the T1 and T2 cephalograms was excellent and the landmark identification appeared accurate correct. However, the T1 cephalogram revealed that only the second and third molars appeared to be in occlusion. In the T2 cephalogram, the third molars were no longer present. Perhaps the removal of third molars facilitated molar intrusion, along with autorotation of the mandible and shortening of the AFH. The other subject had 7.2 mm of prescribed molar intrusion and 3.3 deg of MP-SN reduction, but minimal change in molar vertical position or anterior facial height change. On inspection of the subject's records, the patient displayed differences in head position in the T1 and T2 cephalograms. The T1 cephalogram had two distinct mandibular borders, while the mandibular borders in the T2 cephalogram were coincident. This indicated a canting of the head in one of the radiographs, which may have caused the differences in the measured mandibular plane angles.

There was also a clear outlier in the PMI treatment group that actually had 1.6 mm of planned molar extrusion. This was due to the fact that the molars were out of occlusion at initial presentation and the patient received premolar intrusion instead, which still resulted in a virtual "bite jump" in the ClinCheck® software plan. The amount of planned molar movement also differed significantly based on the presence or absence of virtual bite blocks, and PMI-BB patients had significantly more planned molar intrusion.

As mentioned earlier, the patients in this study were generally mild to moderate openbites. In more severe openbite cases where greater molar intrusion is desired, TADs or orthognathic surgery might be more robust and predictable techniques. Studies on skeletal anchorage reported molar intrusion ranging from 2.3-3.6 mm.[8,29] On average, MP-SN closed 1.2 deg and there was

AFH shortening of 1.6 mm.[29] In comparison, studies on patients treated with LeFort I posterior impaction surgery report superior movement of the maxillary molars by 4.2 mm,[30] as well as MP-SN closure of 5.2 deg and AFH shortening of 3.02 mm.[30] Surgical correction of AOBs can also be accomplished by mandibular bilateral sagittal split osteotomy (BSSO), and studies have reported up to 3.7 deg of mandibular plane closure during surgery.[10]

Treatment stability, indicated by POSI=0, was high (78.6%), but the follow-up period was relatively short. These findings are consistent with those of a meta-analysis that found both non-surgical and surgical treatment modalities to have relatively high treatment stability over 75%.[31] The sample size was too small to compare differences in stability between treatment groups. A larger sample size and longer follow-up period are needed to detect any differences in treatment stability.

LIMITATIONS

We cannot be certain that the sample we acquired was free of selection bias, but we did attempt to consecutively identify all patients that would qualify from our participating offices. 6 patients in this sample were 18 years or younger during their treatment, which could theoretically have an effect on the vertical millimetric measurements in these patients. However, these adolescent patients were equally distributed among the PMI and no-PMI treatment groups, so any effect due to growth would be similar for both groups. In addition, all cephalometric studies are subject to issues related to head positioning, magnification, and landmark identification. The number of subjects with molar bite blocks was small (N=7) and contributed from only one practitioner, and only 1/3 of the patients had long-term data.

CONCLUSIONS

Patients with no-PMI displayed minimal mean changes in vertical molar movements, mandibular plane angle, and anterior facial height. Planned molar intrusion appeared to result in a small, but statistically significant, amount of mean molar intrusion in the multivariate analysis. The amount of planned molar intrusion was not well correlated with the amount of measured molar intrusion, mandibular plane closure, or decrease in AFH. In all patients, incisor retroclination and extrusion appeared to be the primary mechanism of AOB correction. Treatment success rates were high, suggesting that aligners are an effective appliance for the correction of mild to moderate AOBs. Stability of openbite correction with aligners was similar to rates reported for fixed appliances in the literature, but only a third of patients had follow-up data, and the post-treatment period was relatively short.

FIGURES AND TABLES

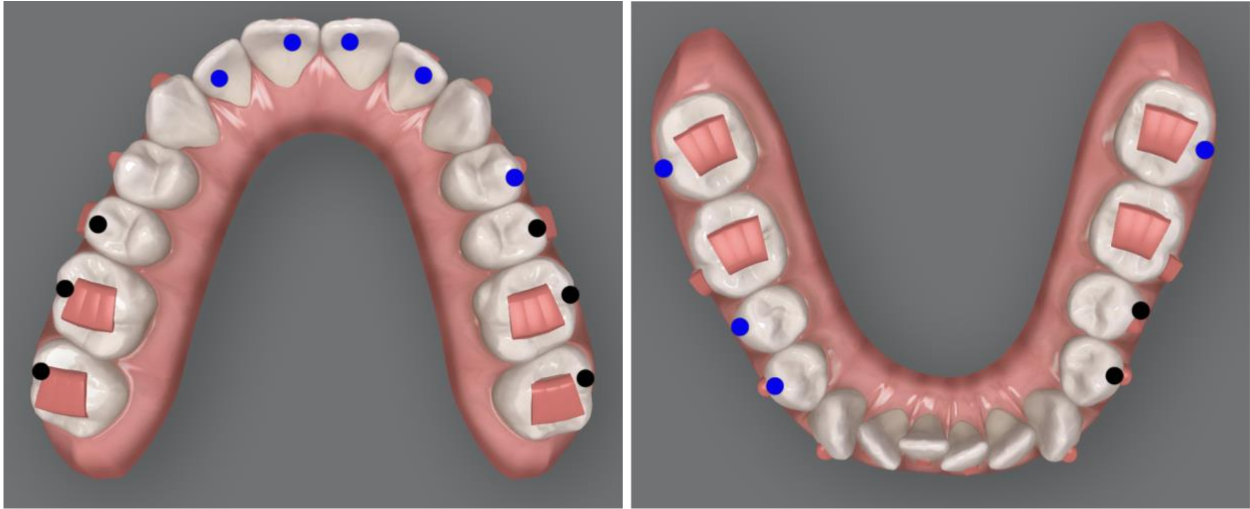

Figure 1. Virtual posterior bite blocks on the occlusal of maxillary and mandibular second molars.

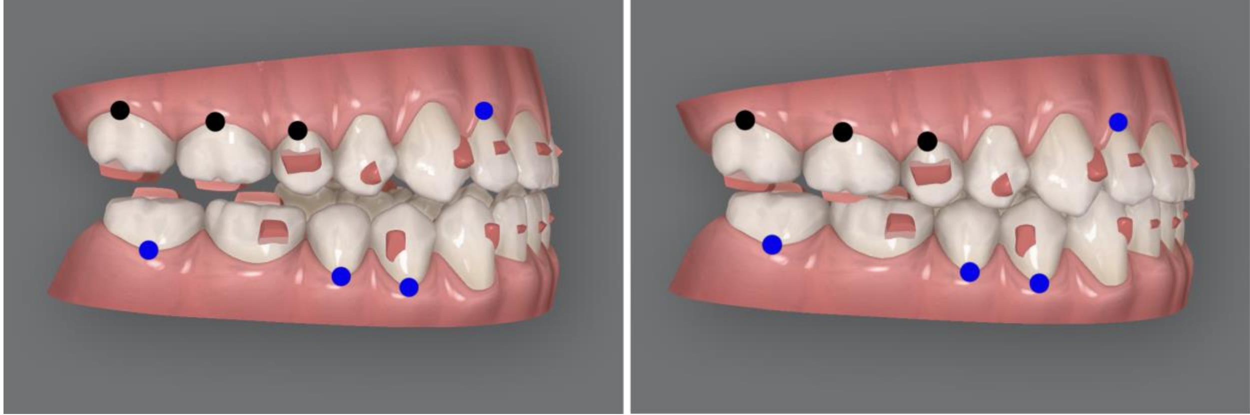

Figure 2. Before and after virtual bite “jump” simulated in ClinCheck® software plan for the same patient as in Figure 1.

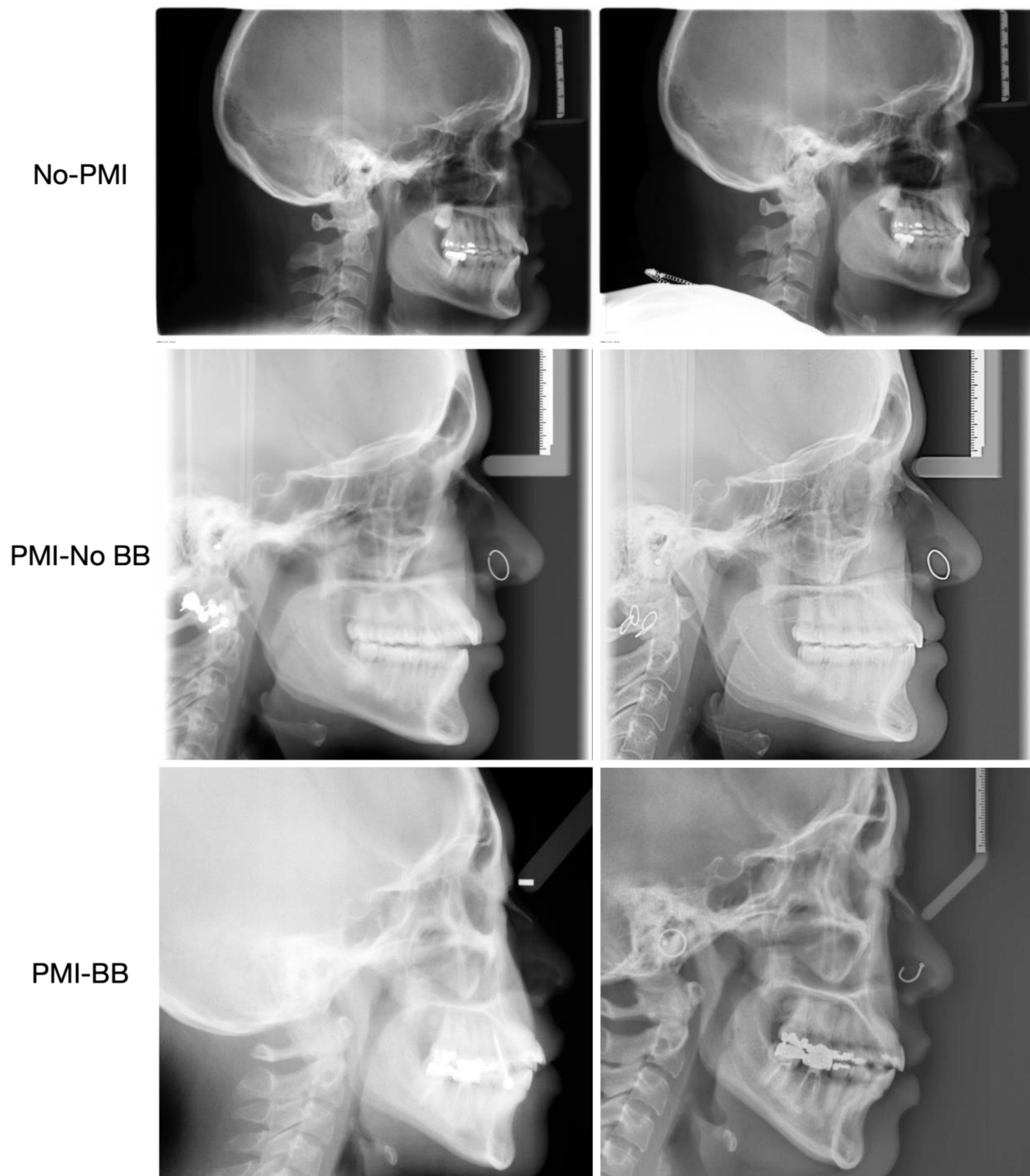

Figure 3. Cephalograms of representative patients from each treatment category: No-PMI, PMI-No BB, PMI-BB.

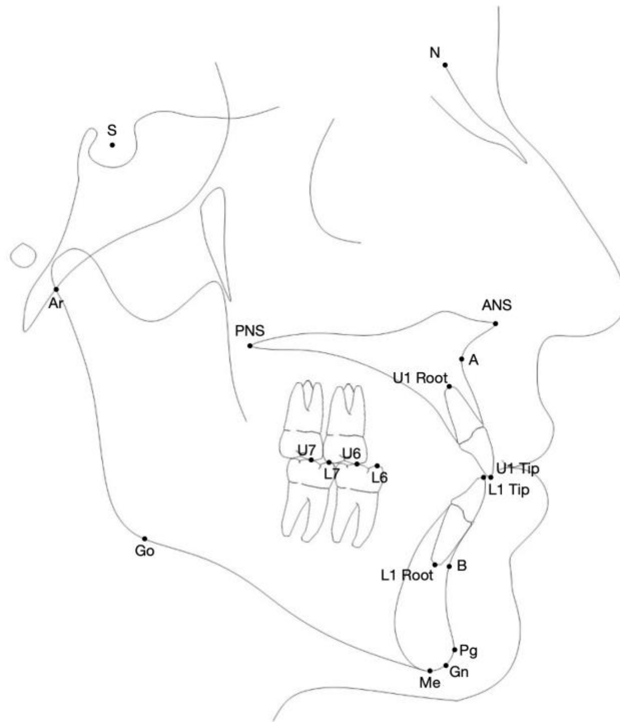

Figure 4. Summary of cephalometric landmarks identified on pre- and post-treatment lateral cephalograms: sella (S), nasion (N), anterior nasal spine (ANS), posterior nasal spine (PNS), pogonion (Pg), gnathion (Gn), menton (Me), anatomic gonion (Go), articulare (Ar), A-point (A), B-point (B), incisal edge of the maxillary incisor (U1 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), occlusal of the maxillary first molar (U6), occlusal of the mandibular first molar (L6), occlusal of the maxillary second molar (U7), occlusal of the mandibular second molar (L7).

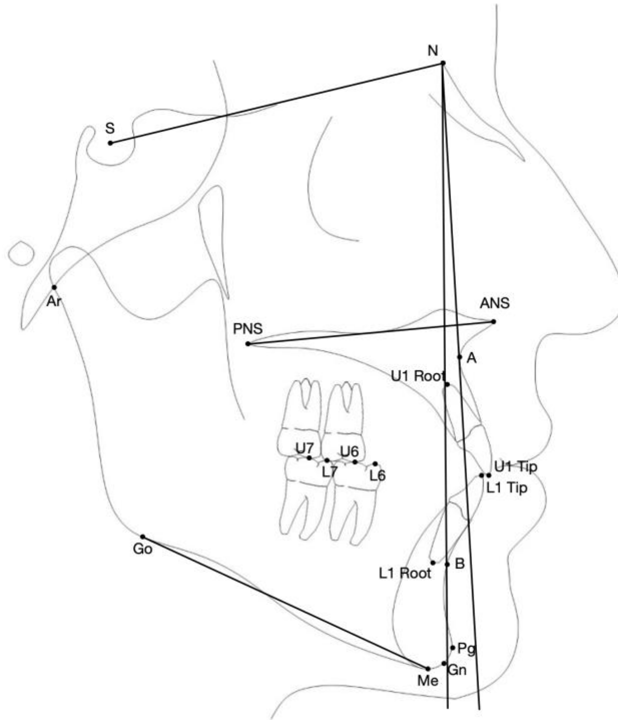

Figure 5. Summary of cephalometric reference planes: sella-nasion (S-N), palatal plane (ANS-PNS), mandibular plane (Go-Me), Nasion – A point, Nasion – B point.

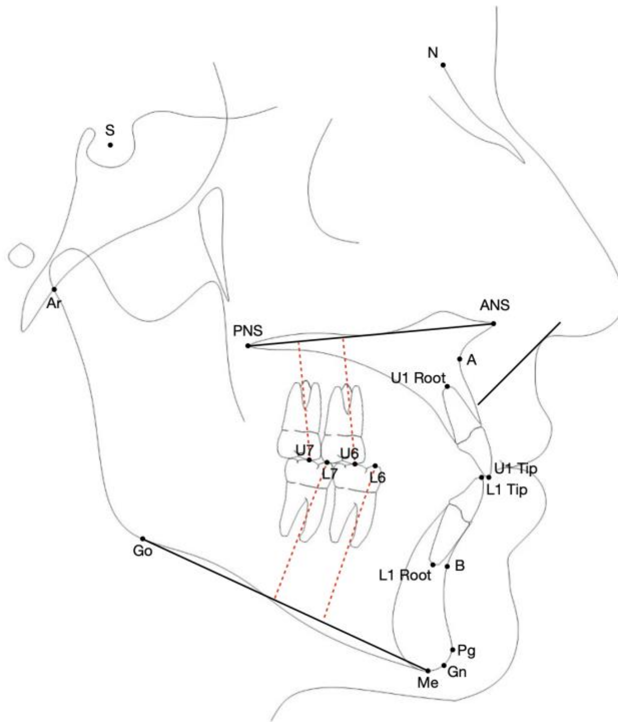

Figure 6. Summary of molar vertical position measurements: U7-PP (mm), U7-SN (mm), U6-PP (mm), U6-SN (mm), L7-MP (mm), L6-MP (mm).

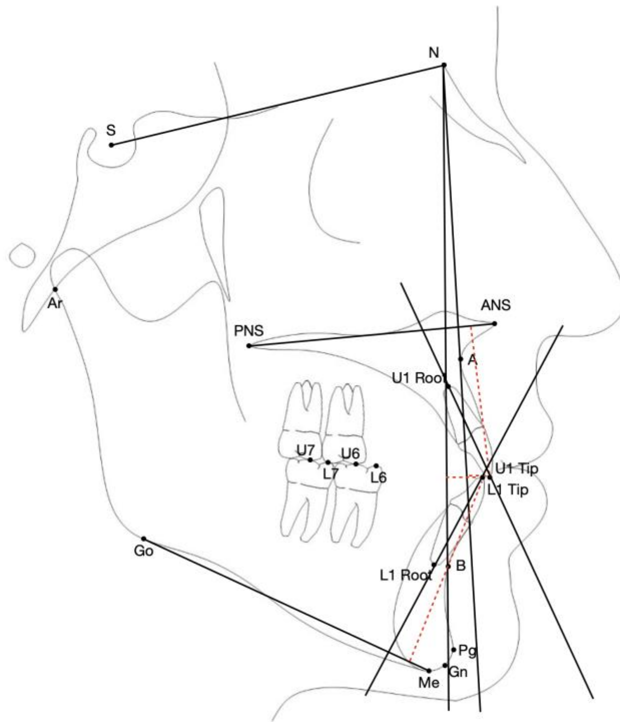

Figure 7. Summary of incisor millimetric position measurements: U1-NA (mm), L1-NB (mm), U1-PP (mm), U1-SN (mm), L1-MP (mm).

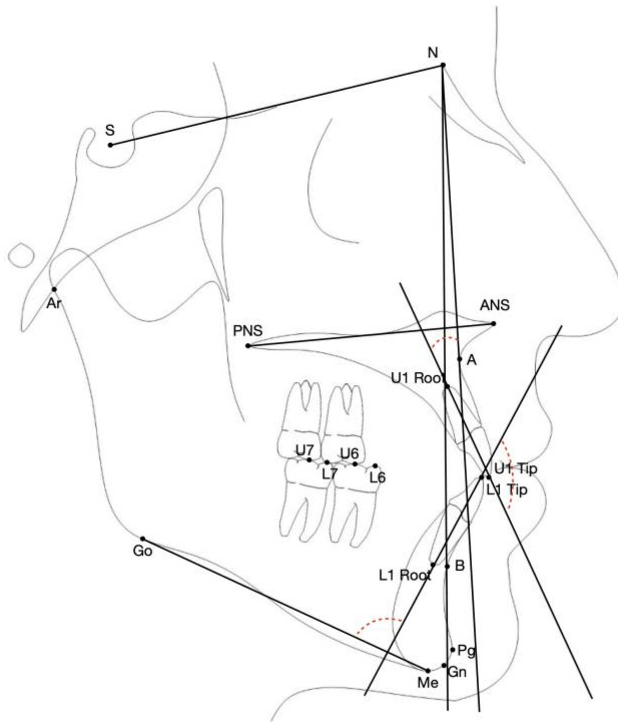

Figure 8. Summary of incisor angulation measurements: U1-NA (deg), L1-NB (deg), IMPA (L1-MP) (deg), interincisal angle (U1-L1) (deg).

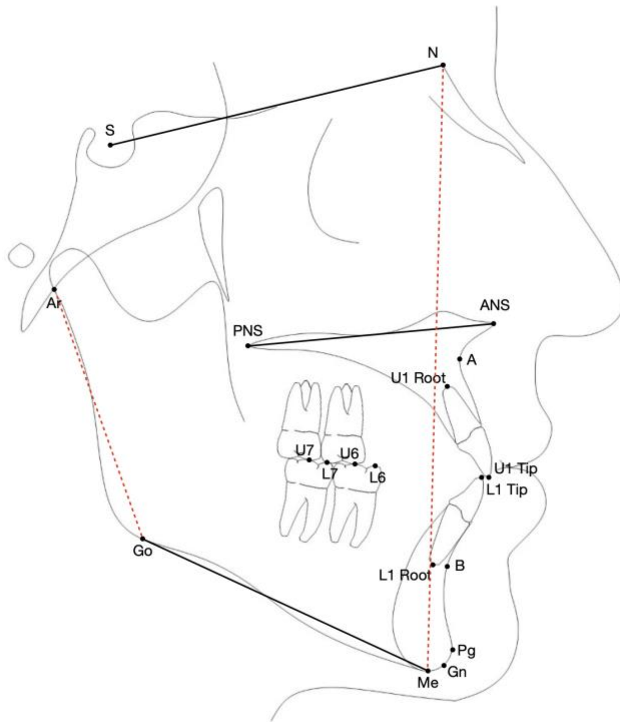

Figure 9. Summary of skeletal measurements: AFH (Na-Me) (mm), PFH (Ar-Go) (mm).

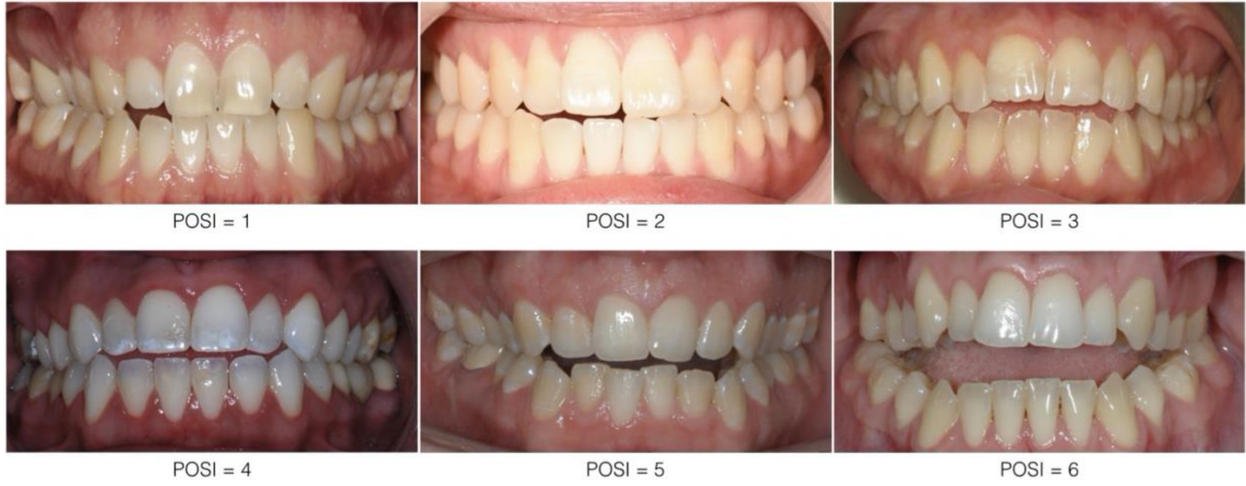

Figure 10. Photographic Openbite Severity Index.

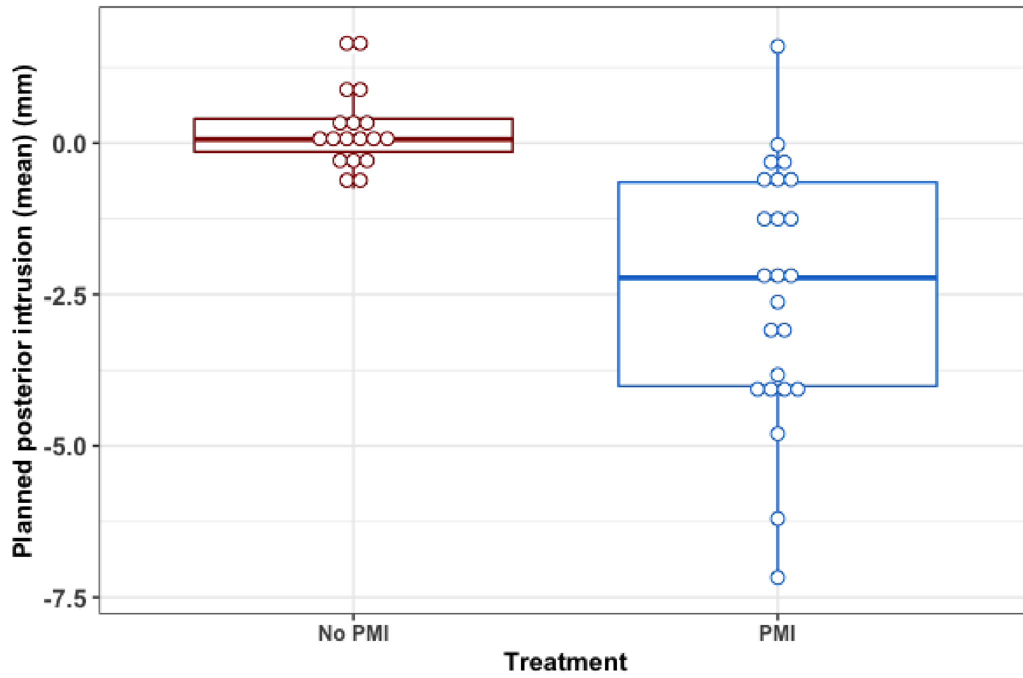

Figure 11. Box-plot comparing the amount of planned molar movement (mean) among No-PMI and PMI patients.

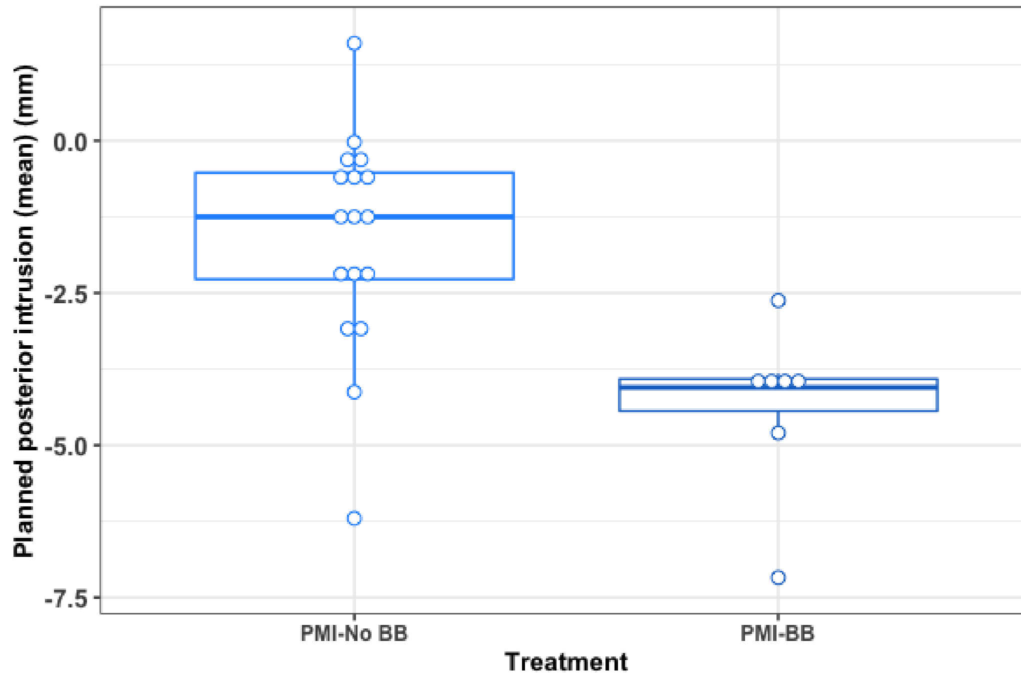

Figure 12. Box-plot comparing the amount of planned molar intrusion (mean) among PMI-No BB and PMI-BB patients.

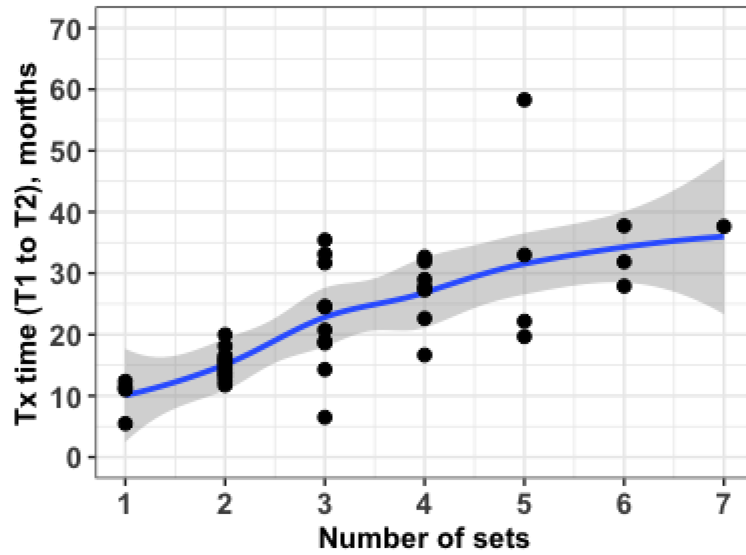

Figure 13. Correlation between number of sets and treatment time in months (Spearman rank correlation coefficient = 0.80) (p-value < 0.0001).

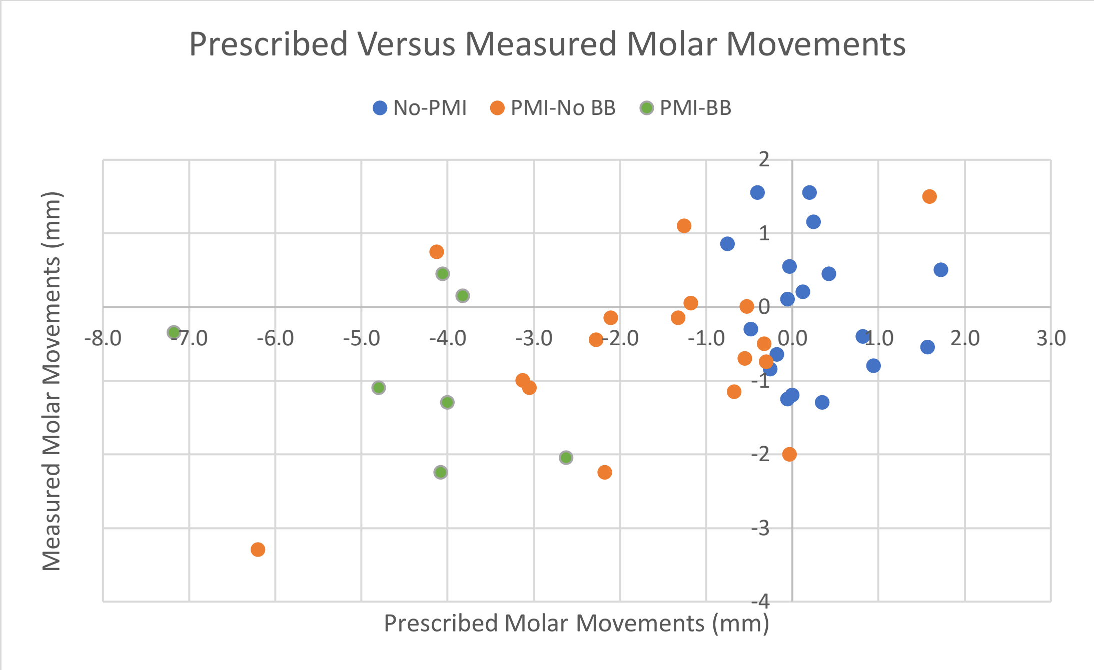

Figure 14. Scatterplot showing prescribed versus measured molar movements for No-PMI, PMI-No BB, and PMI-BB treatment groups. Spearman's rank correlation coefficient for all treatment groups=0.28 (p-value=0.070). Spearman's rank correlation coefficient for PMI treatment groups=0.20 (p-value=0.35).

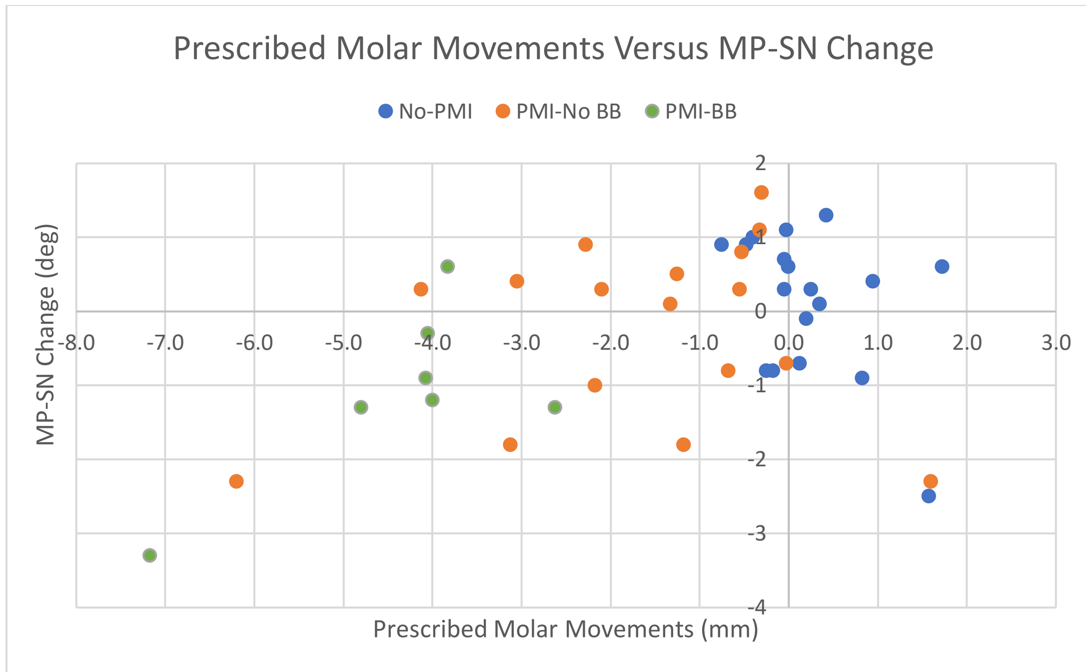

Figure 15. Scatterplot showing prescribed molar movements (mm) versus measured MP-SN (deg) change for No-PMI, PMI-No BB, and PMI-BB treatment groups. Spearman's rank correlation coefficient for all treatment groups=0.23 (p-value=0.14). Spearman's rank correlation coefficient for PMI treatment groups=0.37 (p-value=0.079).

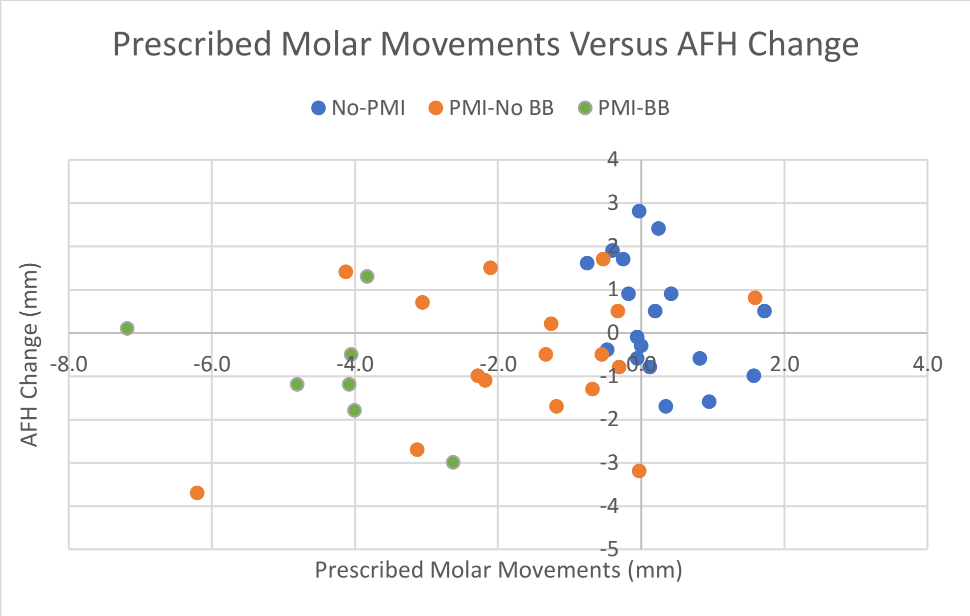

Figure 16. Scatterplot showing prescribed molar movements (mm) versus measured AFH (mm) change for No-PMI, PMI-No BB, and PMI-BB treatment groups. Spearman's rank correlation coefficient for all treatment groups=0.20 (p-value=0.20). Spearman's rank correlation coefficient for PMI treatment groups=0.15 (p-value=0.47).

	Overall, N=42[1]	No-PMI, N=18[1]	PMI, N=24[1]			p-value[2]
Gender						0.93
Female	23 (54.8%)	10 (55.6%)	13 (54.2%)			
Male	19 (45.2%)	8 (44.4%)	11 (45.8%)			

	Overall, N=42[1]	No-PMI, N=18[1]	PMI, N=24[1]	Difference[3]	95% CI[34]	p-value[3]
Age at T1, years				1.0	-6.9, 9.0	0.79
Mean (SD)	30.2 (11.9)	30.8 (13.7)	29.8 (10.6)			
Median (IQR)	27.9 (23.7, 34.8)	27.1 (23.0, 34.2)	28.4 (24.1, 35.1)			
Range	13.2, 63.4	13.9, 63.4	13.2, 58.9			
Age at T2, years				0.4	-7.5, 8.3	0.92
Mean (SD)	32.1 (11.8)	32.3 (13.8)	31.9 (10.5)			
Median (IQR)	30.0 (25.2, 37.3)	28.2 (25.1, 35.6)	30.6 (25.9, 37.3)			
Range	15.1, 64.5	15.1, 64.5	15.2, 61.2			
Treatment time (T1 to T2), months				-7.6	-14.8, -0.3	0.042*
Mean (SD)	22.8 (12.6)	18.5 (9.6)	26.1 (13.8)			
Median (IQR)	19.3 (14.3, 28.7)	14.6 (12.4, 19.7)	23.6 (16.5, 29.7)			
Range	5.5, 68.9	5.5, 37.6	6.5, 68.9			
Arch length, T1						
Severe ALD[5] (7+ mm)	5 (11.9%)	2 (11.1%)	3 (12.5%)			
Moderate ALD (4-6 mm)	6 (14.3%)	2 (11.1%)	4 (16.7%)			
Mild ALD (1-3 mm)	18 (42.9%)	5 (27.8%)	13 (54.2%)			
Adequate arch length (0 mm)	10 (23.8%)	8 (44.4%)	2 (8.3%)			
Mild ALE[6] (1-3 mm)	3 (7.1%)	1 (5.6%)	2 (8.3%)			

[1]N (%)
[2]Pearson’s Chi-squared test; Fisher’s exact test
[3]Welch Two Sample t-test
[4]CI = Confidence Interval
5Arch Length Deficiency
[6]Arch Length Excess

Table 1. Summary of patient and treatment characteristics.

	Overall, N=42[1]	No-PMI, N=18[1]	PMI, N=24[1]	p-value[2]	PMI-No BB, N=17[1]	PMI-BB, N=7[1]	p-value[3]
				0.005*			0.003*
Office A	4 (9.5%)	0 (0.0%)	4 (16.7%)		4 (23.5%)	0 (0.0%)	
Office B	10 (23.8%)	8 (44.4%)	2 (8.3%)		2 (11.8%)	0 (0.0%)	
Office C	10 (23.8%)	1 (5.6%)	9 (37.5%)		2 (11.8%)	7 (100.0%)	
Office D	4 (9.5%)	1 (5.6%)	3 (12.5%)		3 (17.6%)	0 (0.0%)	
Office E	12 (28.6%)	7 (38.9%)	5 (20.8%)		5 (29.4%)	0 (0.0%)	
U. of Washington	2 (4.8%)	1 (5.6%)	1 (4.2%)		1 (5.9%)	0 (0.0%)	

[1]n (%)
[2]Pearson's Chi-squared test; Fisher's exact test
[3]Fisher's exact test

Table 2. Summary of office characteristics.

	Overall, N = 42[1]	No-PMI, N = 18	PMI, N = 24	p-value[2]
Arch length, T1				0.015*
Crowding	29 (69.0%)	9 (50.0%)	20 (83.3%)	
Adequate Arch Length	10 (23.8%)	8 (44.4%)	2 (8.3%)	
Spacing	3 (7.1%)	1 (5.6%)	2 (8.3%)	

[1]N (%)
[2]Fisher's exact test

Table 3. Arch length assessment by treatment type.

	Overall, N = 42[1]	No-PMI, N = 18	PMI, N = 24	p-value[2]
Prescribed molar movement (mean)				<0.001*
Mean (SD)	-1.3 (2.1)	0.2 (0.7)	-2.4 (2.1)	
Median (IQR)	-0.5 (-2.5, 0.0)	0.1 (-0.1, 0.4)	-2.2 (-4.0, -0.6)	
Range	-7.2, 1.7	-0.8, 1.7	-7.2, 1.6	
Planned molar movement (maximum)				
Mean (SD)			-3.4 (2.1)	
Median (IQR)			-2.8 (-4.8, -1.9)	
Range			-9.0, -0.6	

[1]c("Mean (SD)", "Median (IQR)", "Range")
[2]Wilcoxon rank sum test

Table 4. Amount of planned molar movement (mean and maximum) among No-PMI and PMI patients. (+) = extrusion, (-) = intrusion.

	Overall, N = 24	PMI-No BB, N = 17	PMI-BB, N=7	p-value[2]
Prescribed molar movement (mean)				0.002*
Mean (SD)	-2.4 (2.1)	-1.6 (1.8)	-4.4 (1.4)	
Median (IQR)	-2.2 (-4.0, -0.6)	-1.2 (-2.3, -0.5)	-4.0 (-4.4, -3.9)	
Range	-7.2, 1.6	-6.2, 1.6	-7.2, -2.6	

[1]c("Mean (SD)", "Median (IQR)", "Range")
[2]Wilcoxon rank sum test

Table 5. Amount of prescribed molar intrusion (mean) among PMI-No BB and PMI-BB patients. (+) = extrusion, (-) = intrusion.

	Overall, N = 42[1]	No-PMI, N = 18	PMI, N = 24	p-value[2]
Sets of aligners				0.008*
1	4 (9.5%)	4 (22.2%)	0 (0.0%)	
2	13 (31.0%)	8 (44.4%)	5 (20.8%)	
3	10 (23.8%)	4 (22.2%)	6 (25.0%)	
4	7 (16.7%)	1 (5.6%)	6 (25.0%)	
5	4 (9.5%)	0 (0.0%)	4 (16.7%)	
6	3 (7.1%)	0 (0.0%)	3 (12.5%)	
7	1 (2.4%)	1 (5.6%)	0 (0.0%)	

[1]c("Mean (SD)", "Median (IQR)", "Range")
[2]Fisher's exact test

Table 6. Number of sets of aligners by treatment type.

	Overall, N = 42[1]	No-PMI N = 18	PMI, N = 24	p-value[2]
Number of active aligners				<0.001*
Mean (SD)	60.2 (31.6)	41.6 (23.8)	74.1 (29.8)	
Median (IQR)	53.0 (39.5, 74.5)	41.0 (21.8, 50.0)	72.0 (52.0, 91.2)	
Range	10.0, 155.0	10.0, 104.0	30.0, 155.0	

[1]c("Mean (SD)", "Median (IQR)", "Range")
[2]Wilcoxon rank sum test

Table 7. Number of active aligners by treatment type.

			T1					T2		
Variable	**No-PMI, N = 18[1]**	**PMI, N = 24[1]**	**Difference[2]**	**95% CI[23]**	**p-value[2]**	**No-PMI, N = 18[1]**	**PMI, N = 24[1]**	**Difference[2]**	**95% CI[23]**	**p-value[2]**
SNA (deg)	80.8 (3.5)	81.1 (3.6)	-0.4	-2.6, 1.9	0.74	80.7 (3.4)	81.1 (4.1)	-0.5	-2.8, 1.9	0.69
SNB (deg)	77.0 (3.6)	78.9 (4.4)	-1.9	-4.4, 0.6	0.13	77.0 (3.8)	79.2 (4.5)	-2.3	-4.9, 0.3	0.081
ANB (deg)	3.8 (2.4)	2.3 (2.5)	1.5	0.0, 3.0	0.057	3.7 (2.3)	1.9 (2.5)	1.8	0.3, 3.3	0.017*
MP-SN (deg)	35.9 (7.1)	37.1 (6.2)	-1.2	-5.5, 3.1	0.57	36.0 (7.1)	36.6 (6.3)	-0.6	-4.9, 3.7	0.79
SN-PP (deg)	8.0 (3.9)	7.3 (4.9)	0.7	-2.0, 3.4	0.60	8.2 (3.7)	7.4 (4.2)	0.8	-1.7, 3.2	0.54
Upper face (mm)	52.2 (4.2)	52.8 (3.0)	-0.5	-2.9, 1.8	0.65	52.6 (4.4)	52.8 (3.0)	-0.2	-2.6, 2.2	0.87
Lower face (mm)	70.5 (5.4)	71.9 (4.9)	-1.4	-4.7, 1.9	0.40	70.5 (5.6)	71.2 (5.3)	-0.8	-4.2, 2.7	0.66
AFH (mm)	122.7 (7.7)	124.7 (6.1)	-1.9	-6.4, 2.5	0.38	123.1 (8.3)	124.0 (6.6)	-0.9	-5.8, 3.9	0.69
PFH (mm)	47.9 (5.7)	47.9 (6.8)	0.0	-3.9, 3.9	>0.99	46.8 (5.9)	47.8 (6.4)	-1.0	-4.8, 2.8	0.60
U1-NA (deg)	23.6 (7.3)	27.9 (7.8)	-4.2	-9.0, 0.5	0.079	18.3 (6.6)	24.1 (5.4)	-5.8	-9.7, -1.9	0.005*
U1-NA (mm)	5.5 (2.6)	7.1 (2.7)	-1.6	-3.2, 0.1	0.063	4.0 (2.2)	6.3 (2.3)	-2.3	-3.7, -0.9	0.002*
L1-NB (deg)	29.5 (7.0)	29.4 (8.9)	0.1	-4.8, 5.1	0.96	27.5 (6.5)	26.2 (8.1)	1.3	-3.3, 5.8	0.57
L1-NB (mm)	7.2 (2.5)	7.2 (2.9)	0.0	-1.7, 1.7	0.99	6.8 (2.9)	6.5 (2.9)	0.3	-1.5, 2.1	0.76
IMPA (deg)	96.6 (6.5)	93.4 (9.2)	3.2	-1.7, 8.1	0.19	94.6 (5.9)	90.4 (8.4)	4.2	-0.3, 8.6	0.067
Overbite (mm)	-0.7 (1.0)	-1.8 (1.6)	1.1	0.3, 1.9	0.011*	1.9 (0.6)	1.4 (0.6)	0.4	0.1, 0.8	0.028*
Overjet (mm)	3.7 (1.4)	3.1 (1.8)	0.6	-0.4, 1.6	0.25	2.8 (0.5)	2.7 (0.6)	0.1	-0.2, 0.4	0.55
U6-PP[4] (mm)	23.5 (2.6)	25.2 (3.5)	-	-	-	23.5 (2.4)	24.7 (3.8)	-	-	-
U7-PP[4] (mm)	20.6 (3.1)	23.1 (3.0)	-	-	-	20.7 (3.4)	23.0 (3.1)	-	-	-
L6-MP[4] (mm)	32.5 (3.1)	31.8 (3.6)	-	-	-	32.5 (3.2)	31.4 (3.4)	-	-	-
L7-MP[4] (mm)	30.0 (3.2)	28.9 (3.9)	-	-	-	29.9 (3.4)	28.5 (3.8)	-	-	-
U1 Tip-SN (mm)	-73.9 (4.7)	-74.5 (4.3)	0.6	-2.2, 3.5	0.66	-75.5 (4.8)	-75.6 (4.4)	0.1	-2.8, 3.1	0.92
U1-PP (mm)	30.4 (3.2)	30.2 (2.9)	0.1	-1.8, 2.1	0.88	31.7 (2.6)	31.3 (3.4)	0.4	-1.5, 2.3	0.68
L1-MP (mm)	41.8 (3.1)	41.7 (3.0)	0.2	-1.8, 2.1	0.87	42.6 (3.4)	42.5 (3.3)	0.2	-2.0, 2.3	0.88
Occ Plane to SN (deg)	18.0 (4.7)	15.8 (5.9)	2.2	-1.2, 5.5	0.19	18.8 (4.4)	16.0 (5.7)	2.8	-0.3, 5.9	0.078

[1]Mean (SD)
[2]Welch Two-Sample t-test
[3]CI = Confidence Interval
[4]Differences not compared due to the use of alternative landmarks in some subjects

Table 8. T1 and T2 summaries for No- PMI and PMI patients.

	T1					T2				
Variable	**PMI-No BB, N = 17**[1]	**PMI-BB, N = 7**[1]	**Difference**[2]	**95% CI**[23]	**p-value**[2]	**PMI-No BB, N = 17**[1]	**PMI-BB, N = 7**[1]	**Difference**[2]	**95% CI**[23]	**p-value**[2]
SNA (deg)	80.9 (4.0)	81.7 (2.4)	-0.7	-3.5, 2.1	0.59	80.8 (4.6)	82.0 (2.6)	-1.2	-4.3, 1.9	0.43
SNB (deg)	78.9 (4.8)	78.9 (3.5)	-0.1	-3.8, 3.7	0.97	79.2 (5.1)	79.3 (3.0)	-0.1	-3.6, 3.4	0.95
ANB (deg)	2.1 (2.4)	2.7 (3.1)	-0.7	-3.6, 2.2	0.62	1.5 (2.2)	2.6 (3.0)	-1.1	-4.0, 1.8	0.41
MP-SN (deg)	36.6 (7.0)	38.3 (4.0)	-1.8	-6.5, 2.9	0.44	36.3 (7.3)	37.2 (3.4)	-0.9	-5.5, 3.6	0.67
SN-PP (deg)	8.1 (3.7)	5.4 (7.0)	2.7	-3.7, 9.2	0.35	8.0 (3.6)	5.9 (5.5)	2.1	-3.0, 7.3	0.37
Upper face (mm)	52.6 (3.0)	53.2 (3.2)	-0.6	-3.8, 2.5	0.67	52.5 (2.8)	53.6 (3.6)	-1.1	-4.6, 2.3	0.47
Lower face (mm)	71.5 (4.8)	72.9 (5.5)	-1.4	-6.7, 3.9	0.56	71.0 (5.4)	71.7 (5.4)	-0.6	-5.9, 4.7	0.81
AFH (mm)	124.1 (6.7)	126.1 (4.7)	-2.1	-7.2, 3.0	0.40	123.5 (7.1)	125.2 (5.2)	-1.7	-7.3, 3.8	0.52
PFH (mm)	47.9 (7.5)	48.1 (5.3)	-0.2	-5.9, 5.5	0.94	47.7 (7.1)	48.0 (4.8)	-0.3	-5.6, 5.0	0.91
U1-NA (deg)	29.4 (8.2)	24.2 (5.6)	5.2	-1.0, 11.4	0.093	24.8 (5.8)	22.4 (4.3)	2.4	-2.2, 6.9	0.28
U1-NA (mm)	7.4 (2.8)	6.2 (2.2)	1.2	-1.1, 3.6	0.28	6.8 (2.1)	5.3 (2.4)	1.4	-0.9, 3.8	0.21
L1-NB (deg)	29.6 (8.6)	28.6 (10.1)	1.0	-8.7, 10.8	0.82	25.9 (7.7)	27.1 (9.5)	-1.3	-10.4, 7.8	0.76
L1-NB (mm)	7.3 (2.6)	6.9 (3.9)	0.4	-3.3, 4.1	0.82	6.5 (2.8)	6.6 (3.3)	-0.1	-3.3, 3.0	0.94
IMPA (deg)	94.2 (8.8)	91.4 (10.6)	2.8	-7.3, 13.0	0.55	90.3 (8.4)	90.6 (9.3)	-0.3	-9.2, 8.7	0.95
Overbite (mm)	-1.8 (1.8)	-1.7 (0.9)	-0.1	-1.2, 1.0	0.86	1.6 (0.5)	1.1 (0.8)	0.5	-0.2, 1.2	0.15
Overjet (mm)	3.0 (1.7)	3.3 (2.2)	-0.2	-2.3, 1.8	0.80	2.7 (0.6)	2.8 (0.6)	0.0	-0.7, 0.6	0.87
U6-PP[4] (mm)	25.3 (3.2)	25.0 (4.4)	-	-	-	25.0 (3.7)	23.8 (4.1)	-	-	-
U7-PP[4] (mm)	23.7 (2.5)	21.5 (3.7)	-	-	-	23.8 (2.4)	20.9 (3.9)	-	-	-
L6-MP[4] (mm)	32.5 (3.3)	29.9 (3.7)	-	-	-	32.0 (3.3)	30.0 (3.6)	-	-	-
L7-MP[4] (mm)	29.8 (3.6)	26.9 (4.2)	-	-	-	29.3 (3.6)	26.6 (3.9)	-	-	-
U1 Tip-SN (mm)	-74.0 (4.7)	-75.6 (2.8)	1.6	-1.7, 4.9	0.33	-75.2 (4.9)	-76.7 (3.1)	1.5	-2.0, 5.0	0.38
U1-PP (mm)	30.0 (3.0)	30.8 (2.8)	-0.8	-3.6, 1.9	0.53	31.2 (3.7)	31.5 (2.7)	-0.3	-3.2, 2.6	0.84
L1-MP (mm)	41.6 (3.5)	41.8 (1.4)	-0.1	-2.2, 1.9	0.89	42.5 (3.9)	42.5 (1.7)	0.0	-2.3, 2.4	0.98
Occ Plane to SN (deg)	16.5 (6.2)	14.2 (5.1)	2.3	-3.0, 7.6	0.36	16.2 (6.2)	15.5 (4.6)	0.7	-4.2, 5.6	0.76

[1]Mean (SD)
[2]Welch Two-Sample t-test
[3]CI = Confidence Interval
[4]Differences not compared due to the use of alternative landmarks in some subjects

Table 9. T1 and T2 summaries for PMI-No BB and PMI-BB patients.

Variable	No-PMI, N = 18[1]	PMI, N = 24[1]	Difference[2]	95% CI[2,3]	p-value[2]
SNA (deg)	-0.1 (0.7)	0.0 (1.4)	-0.1	-0.8, 0.6	0.79
SNB (deg)	0.0 (0.6)	0.3 (1.0)	-0.4	-0.9, 0.1	0.12
ANB (deg)	-0.1 (0.6)	-0.4 (0.8)	0.3	-0.1, 0.8	0.13
MP-SN (deg)	0.1 (1.0)	-0.5 (1.3)	0.6	-0.1, 1.3	0.069
SN-PP (deg)	0.1 (0.9)	0.1 (1.6)	0.0	-0.8, 0.8	0.91
Upper face (mm)	0.4 (0.8)	0.1 (1.0)	0.3	-0.2, 0.9	0.24
Lower face (mm)	-0.1 (0.9)	-0.7 (1.5)	0.6	-0.1, 1.4	0.11
AFH (mm)	0.3 (1.3)	-0.7 (1.5)	1.0	0.1, 1.9	0.030*
PFH (mm)	-1.1 (1.9)	-0.1 (1.9)	-1.0	-2.2, 0.2	0.10
U1-NA (deg)	-5.3 (7.1)	-3.8 (6.0)	-1.6	-5.8, 2.7	0.46
U1-NA (mm)	-1.5 (1.7)	-0.7 (1.4)	-0.8	-1.8, 0.2	0.13
L1-NB (deg)	-2.0 (3.9)	-3.1 (6.6)	1.2	-2.1, 4.5	0.48
L1-NB (mm)	-0.4 (1.1)	-0.6 (1.7)	0.3	-0.6, 1.2	0.51
IMPA	-2.0 (3.8)	-3.0 (6.7)	0.9	-2.3, 4.2	0.56
Overbite (mm)	2.6 (1.1)	3.2 (1.7)	-0.6	-1.5, 0.2	0.15
Overjet (mm)	-0.9 (1.5)	-0.4 (1.9)	-0.5	-1.5, 0.6	0.36
U6-PP (mm)	-0.1 (1.1)	-0.6 (1.0)	0.5	-0.2, 1.2	0.14
U7-PP (mm)	0.1 (1.1)	-0.1 (1.0)	0.2	-0.5, 0.8	0.61
L6-MP (mm)	0.0 (0.7)	-0.3 (0.8)	0.4	-0.1, 0.8	0.15
L7-MP (mm)	-0.1 (0.8)	-0.4 (0.9)	0.3	-0.2, 0.8	0.23
U1-PP (mm)	1.3 (1.3)	1.1 (1.3)	0.2	-0.6, 1.1	0.56
L1-MP (mm)	0.8 (0.7)	0.8 (1.1)	0.0	-0.6, 0.6	>0.99
Occ Plane to SN (deg)	0.8 (1.5)	0.2 (1.8)	0.6	-0.4, 1.7	0.22

[1]Mean (SD)

[2]Welch Two Sample t-test

[3]CI = Confidence Interval

Table 10. Cephalometric treatment changes (T2-T1) for No-PMI and PMI patients.

Variable	PMI-No BB, N = 17[1]	PMI-BB, N = 7[1]	Difference[2]	95% CI[23]	p-value[2]
SNA (deg)	-0.2 (1.4)	0.3 (1.4)	-0.5	-1.8, 0.9	0.48
SNB (deg)	0.3 (1.0)	0.4 (1.0)	0.0	-1.1, 1.0	0.94
ANB (deg)	-0.5 (0.8)	-0.1 (1.0)	-0.4	-1.4, 0.5	0.33
MP-SN (deg)	-0.3 (1.2)	-1.1 (1.2)	0.8	-0.3, 2.0	0.15
SN-PP (deg)	-0.1 (1.2)	0.5 (2.3)	-0.6	-2.8, 1.6	0.53
Upper face (mm)	-0.1 (1.1)	0.4 (0.8)	-0.5	-1.4, 0.3	0.21
Lower face (mm)	-0.4 (1.6)	-1.3 (1.1)	0.8	-0.4, 2.0	0.17
AFH (mm)	-0.6 (1.6)	-0.9 (1.4)	0.3	-1.1, 1.7	0.62
PFH (mm)	-0.1 (2.2)	0.0 (1.1)	-0.1	-1.5, 1.3	0.92
U1-NA (deg)	-4.6 (6.5)	-1.8 (4.6)	-2.8	-7.8, 2.1	0.25
U1-NA (mm)	-0.7 (1.5)	-0.8 (1.2)	0.2	-1.1, 1.4	0.76
L1-NB (deg)	-3.8 (7.3)	-1.5 (4.2)	-2.3	-7.3, 2.7	0.35
L1-NB (mm)	-0.8 (1.9)	-0.3 (1.5)	-0.5	-2.0, 1.0	0.50
IMPA	-3.9 (7.3)	-0.8 (4.6)	-3.1	-8.3, 2.1	0.23
Overbite (mm)	3.4 (1.8)	2.8 (1.5)	0.6	-0.9, 2.1	0.40
Overjet (mm)	-0.3 (1.9)	-0.5 (2.0)	0.2	-1.7, 2.1	0.83
U6-PP (mm)	-0.3 (0.9)	-1.2 (1.0)	0.8	-0.1, 1.8	0.085
U7-PP (mm)	0.1 (1.0)	-0.5 (0.7)	0.6	-0.1, 1.4	0.094
L6-MP (mm)	-0.5 (0.9)	0.1 (0.5)	-0.6	-1.2, 0.0	0.046*
L7-MP (mm)	-0.5 (0.9)	-0.3 (1.0)	-0.2	-1.2, 0.8	0.67
U1-PP (mm)	1.2 (1.3)	0.7 (1.3)	0.5	-0.7, 1.8	0.36
L1-MP (mm)	0.9 (1.2)	0.7 (0.9)	0.2	-0.8, 1.1	0.72
Occ Plane to SN (deg)	-0.3 (1.7)	1.3 (1.4)	-1.6	-3.0, -0.2	0.031*

[1]Mean (SD)

[2]Welch Two Sample t-test

[3]CI = Confidence Interval

Table 11. Cephalometric treatment changes (T2-T1) for PMI-No BB and PMI-BB patients.

Characteristic	N	Beta	95% CI[1]	p-value
Treatment	42			0.034*
No-PMI		—	—	
PMI		-0.72	-1.4, -0.08	
Overbite at T1	42	0.03	-0.19, 0.26	0.77
MP-SN at T1	42	0.02	-0.03, 0.07	0.37
Crowding at T1 (mm)	42	-0.02	-0.13, 0.09	0.73
Age at start (years)	42	-0.03	-0.06, -0.01	0.011*
Sex	42			
F		—	—	
M		0.70	0.09, 1.3	0.032*

[1]CI = Confidence Interval

Table 12. Linear regression for the effect of treatment type, No-PMI and PMI, on measured molar intrusion (mm), controlling for potential confounding variables.

	Overall, N=15[1]	No-PMI, N=10	PMI, N=5
POSI Scores			
0	12 (80.0%)	8 (80%)	4 (80.0%)
1	2 (13.3%)	2 (20%)	0 (0%)
2	0 (0%)	0 (0%)	0 (0%)
3	0 (0%)	0 (0%)	0 (0%)
4	1 (6.7%)	0 (0%)	1 (20.0%)
5	0 (0%)	0 (0%)	0 (0%)
6	0 (0%)	0 (0%)	0 (0%)

[1]N (%)

Table 13. POSI scores for T3 frontal photographs by treatment type.

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