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The National Dental Practice-Based Research Network Adult Anterior Open Bite Study: Treatment success

Lauren S. Todoki,[a] Samuel A. Finkleman,[a] Ellen Funkhouser,[b] Geoffrey M. Greenlee,[c] Kelly W. Choi,[d] Hsiu-Ching Ko,[c] Hsuan-Fang Wang,[c,e] Peter A. Shapiro,[c] Roozbeh Khosravi,[c] Camille Baltuck,[f] Veerasathpurush Allareddy,[g] Calogero Dolce,[h] Chung How Kau,[i] Kyungsup Shin,[j] Jaime de Jesus-Vinas,[k] Michael Vermette,[l] Cameron Jolley,[m] the National Dental Practice-Based Research Network Collaborative Group,[†] and Greg J. Huang[c]

Seattle, Wash, and Birmingham, Ala, and Santa Rosa, Calif, and Taipei, Taiwan, and Portland, Ore, and Chicago, Ill, and Gainesville, Fla, and Iowa City, Iowa, and San Juan, Puerto Rico, and Concord, NH, and Trophy Club, TX

Introduction: Anterior open bite (AOB) continues to be a challenging malocclusion for orthodontists to treat and retain long-term. There is no consensus on which treatment modality is most successful. This study reports on the overall success rate of AOB orthodontic treatment in the adult population across the United States, as well as 4 major treatment modalities and other factors that may influence treatment success. **Methods:** Practitioners and their adult patients with AOB were recruited through the National Dental Practice-Based Research Network. Patient dentofacial and demographic characteristics, practitioner demographic and practice characteristics, and factors relating to orthodontic treatment were reported. Treatment success was determined from posttreatment (T2) lateral cephalometric films and intraoral frontal photographs. Treatment was categorized into 4 main groups: aligners, fixed appliances, temporary anchorage devices (TADs), and orthognathic surgery. Extractions were also evaluated. Bivariate and multivariable models were used to investigate the association between treatment success and treatment modality, pretreatment (T1) dentofacial characteristics, patient and practitioner demographics, and practice characteristics, adjusting for clustering of patients within practice. **Results:** A total of 254 patients, enrolled by 84 practitioners, contributed to T2 data for this study. There were 29 patients in the aligner group, 152 in fixed appliances, 20 in TADs, and 53 in surgery. A total of 49 patients underwent extractions of teeth other than third molars. Ninety-three percent finished treatment with a positive overbite on the T2 lateral cephalogram, and 84% finished with a positive vertical overlap of all incisors. The small number of aligners and TAD patients limited the ability to compare success rates in these groups. Patients treated with orthognathic surgery had a higher rate of success compared with those treated with fixed appliances only. Treatment success was also associated with academic practice setting, T1 mandibular plane angle $\leq 30°$, no to mild T1 crowding, and treatment duration <30 months. **Conclusions:** The overall success of orthodontic treatment in adult patients with AOB who participated in this study was very high. Orthognathic surgery was the only treatment modality that exhibited a statistically higher odds of successful outcomes. Some T1 dentofacial characteristics and treatment factors were associated with the successful closure of AOB. (Am J Orthod Dentofacial Orthop 2020;158:e137-e150)

[a]Private Practice, Seattle, Wash.
[b]Division of Preventive Medicine, School of Medicine, University of Alabama at Birmingham, Birmingham, Ala.
[c]Department of Orthodontics, University of Washington, Seattle, Wash.
[d]Private Practice, Santa Rosa, Calif.
[e]Division of Orthodontics, Department of Dentistry, Far Eastern Memorial Hospital, Taipei, Taiwan.
[f]Western Region, National Dental Practice-Based Research Network, Portland, Ore.
[g]Department of Orthodontics, and Specialty Node, National Dental Practice-Based Research Network, University of Illinois at Chicago, Chicago, Ill.
[h]Department of Orthodontics, University of Florida, Gainesville, Fla.
[i]Department of Orthodontics, University of Alabama at Birmingham, Birmingham, Ala.
[j]Department of Orthodontics, University of Iowa, Iowa City, Iowa.
[k]Private Practice, San Juan, Puerto Rico.
[l]Private Practice, Concord, NH.
[m]Private Practice, Trophy Club, TX.

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The informed consent of all human subjects who participated in this investigation was obtained after the nature of the procedures had been explained fully. An Internet site devoted to details about the nation's network is located at http://NationalDentalPBRN.org and is conducted under the auspices of the National Dental Practice-Based Research Network.

[†]The National Dental Practice-Based Research Network Collaborative Group comprises practitioners, faculty, and staff investigators who contributed to this network activity. A list of these persons are at http://www.nationaldentalpbrn.org/collaborative-group.php.

Address correspondence to: Lauren S. Todoki, Department of Orthodontics, University of Washington, Seattle, WA; e-mail, ltodoki@gmail.com.

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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, because of the altered tongue position on the incisors and the anterior hard palate.[2] Furthermore, AOB development is often associated with unfavorable growth patterns, oral habits (ie, digit sucking and tongue posture), and nasopharyngeal airway obstructions.[3] Because of its complex and multifactorial etiology, AOB continues to be 1 of the most challenging malocclusions for orthodontists to treat and retain successfully.

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.[4] FAs with extrusive mechanics for the anterior teeth can create an overlap between maxillary and mandibular incisors; 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 patients with AOB with orthognathic surgery (SX), especially when a nongrowing, adult patient presents with an AOB that is of skeletal origin. Surgery may involve the maxilla, mandible, or both to skeletally correct the AOB.[5]

In recent decades, the use of temporary anchorage devices (TADs) has become a popular nonsurgical technique for correcting AOB.[6] Miniscrews or miniplates 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.[7]

Clear aligner therapy (ALN) is another recently-developed alternative to traditional FA for AOB. The thickness of the plastic on the occlusal surfaces, in combination with the forces of mastication, is believed to produce an intrusive force on the posterior dentition, which may aid with AOB closure.[8,9] Although several case studies have demonstrated successful AOB correction, molar intrusion has not been confirmed.[10,11]

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 "drawbridge" effect.[12,13] Posterior extractions allow molars to move anteriorly ("wedge effect"), resulting in a closing rotation of the mandible.[6,14]

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.[15,16] 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 purpose of this large observational prospective cohort study, conducted under the auspices of the National Dental Practice-Based Research Network (PBRN), was to explore treatment recommendations, outcomes, and stability of adult patients with AOB. This publication reports on the overall success rate of AOB treatment and explores how treatment success varies with treatment modality, pretreatment (T1) dentofacial characteristics, and patient and practitioner demographic and practice characteristics.

MATERIAL AND METHODS

Dental providers and their adult patients with AOB were recruited from 6 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 at Birmingham 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). In addition, institutional IRB approval was obtained at individual academic settings when required. Practitioners and patients were compensated for their participation in this study. As members of the National Dental PBRN, the practitioners completed a T1 questionnaire that elicited information on their training and practices.

Inclusion criteria for practitioners were as follows: (1) orthodontist or dentist who routinely performs orthodontic treatment, (2) estimates to recruit 3 to 8 adult patients in active treatment for AOB, and expects to have treatment completed within 24 months of enrollment into the study, (3) routinely takes cephalometric radiographs (cephalogram) before and after treatment, (4) able to upload deidentified cephalogram and digital intraoral frontal photographs to a central data repository, (5) affirms that the practice can devote sufficient time in patient scheduling to allow recording of all data required for the study, and (6) does not anticipate retiring, selling the practice, or moving during the study.

Inclusion criteria for patients were as follows: (1) aged at least 18 years at the time of enrollment; (2) must have an AOB, which is defined as at least 1 incisor that does 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; (3) must be in active treatment for AOB, and expect to have treatment completed within 24 months of enrollment into the study; and (4) must have an initial cephalogram (taken before the beginning of treatment). A cephalogram created from a cone-beam computerized tomography scan is acceptable.

Exclusion criteria for patients were as follows: (1) clefts, craniofacial conditions or syndromes; (2) significant physical, mental, or medical conditions that would affect treatment compliance, cooperation, or outcome; (3) expects to move before the completion of the study; and (4) initial treatment plans estimated to be more than 36 months.

T1 questionnaires were completed by practitioners and patients at the enrollment visit to obtain information about patient characteristics, T1 diagnosis, and recommended/accepted treatment. Once active treatment was complete, posttreatment (T2) questionnaires were completed by practitioners and their patients to obtain information about treatment methods used. All study forms can be accessed at https://www.nationaldentalpbrn.org/study-results/#1589299528044-b9cab599-914e.

T1 and T2 lateral cephalometric images were collected. These images were traced using Dolphin Imaging & Management Solutions 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 1 examiner and reviewed by the second examiner (L.S.T. and S.A.F.). Disagreements in landmark identification were resolved using the consensus between the 2 examiners, with a third examiner (K.W.C.) consulting if the 2 examiners could not reach a consensus.

A standard millimetric ruler in the cephalostat was used to calibrate millimetric measurements. When a ruler was present in only 1 of a patient's cephalograms (either T1 or T2), the sella-nasion distance of the lateral cephalogram with the ruler present was used to calibrate the cephalogram without the ruler (n = 13). When a ruler was not present on both a patient's T1 and T2 cephalograms (n = 14), a standard distance for nasion-menton, based on published norms, was used to calibrate the T1 cephalogram.[17,18] The T2 lateral cephalogram was then calibrated using the sella-nasion distance of the T1 lateral cephalogram, as described above.

T1 and T2 intraoral frontal photographs were deidentified and forwarded to the research team at the University of Washington. The Photographic Open

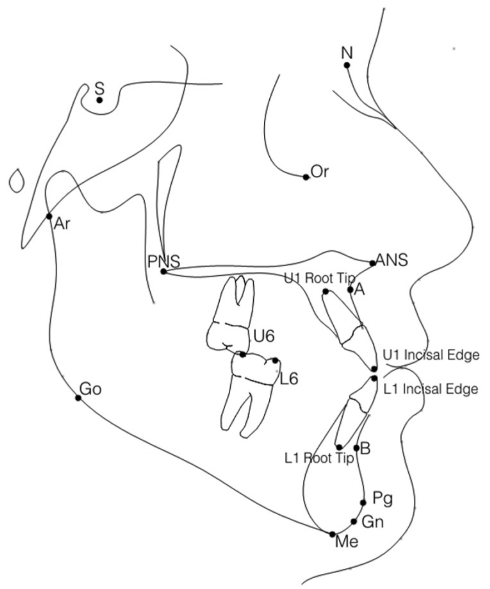

Fig 1. Cephalometric landmarks identified on T1 and T2 lateral cephalograms. *S,* sella; *N,* nasion; *Or,* orbitale; *Ar,* articulare; *PNS,* posterior nasal spine; *ANS,* anterior nasal spine; *U1 Root Tip*, root tip of the maxillary incisor; *A*, A-point; *U6*, mesiobuccal cusp tip of the maxillary first molar; *L6*, mesiobuccal cusp tip of the mandibular first molar; *U1 Incisal Edge*, incisal edge of the maxillary incisor; *L1 Incisal Edge*, incisal edge of the mandibular incisor; *Go*, anatomic gonion; *L1 Root Tip*, root tip of the mandibular incisor; *B*, B-point; *Pg*, pogonion; *Gn*, gnathion; *Me*, menton.

Bite Severity Index (POSI) was developed to score the severity of the patient's T1 AOB and final result using the pre- and T2 intraoral frontal photographs. Seven categories were developed on the basis of the number and type of teeth with vertical overlap (Fig 2): (0) all 4 incisors with positive overlap; (1) 1 or 2 maxillary lateral incisors without vertical overlap (but both maxillary central incisors have vertical overlap); (2) 1 maxillary central incisor without vertical overlap (the other maxillary central has vertical overlap); (3) 2 maxillary central incisors without vertical overlap (at least 1 maxillary lateral has vertical overlap); (4) all 4 maxillary incisors without vertical overlap; (5) all anterior teeth, including canines, without overlap; and (6) all anterior teeth, including canines, plus at least 1 premolar without vertical overlap.

Each image was rated independently by the same 2 examiners, and the scores were compared. Disagreements in ratings were resolved using the consensus between the examiners, with a third examiner consulting if the two could not reach a consensus.

Fig 2. Photographic Open Bite Severity Index.

To calculate intra- and interrater reliability, 10 cephalometric images, and 20 intraoral frontal images were randomly selected. Cephalometric landmarks were identified, and frontal photographic images were rated by each evaluator and repeated 1 month later. Both inter- and intrarater reliability were excellent as determined using intraclass correlations. For the cephalometric analysis, the mean interrater reliability was 97%, and the mean intrarater reliability was 98%. For the POSI, the interrater mean percent agreement was 92.5%, and the mean kappa was 95.5%. The intrarater mean percent agreement was 97%, and the mean kappa was 98.5%.

Statistical analysis

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 T2. The most anterior central incisors were measured; and (2) POSI: intraoral frontal photographs were used to evaluate treatment success—defined by a score of 0 (all 4 incisors with positive overlap) at T2.

Success rates were calculated for the following variables to identify potential factors related to successful AOB treatment: (1) treatment modality (ALN, FA, TAD, SX, and extractions), (2) patient T1 dentofacial characteristics, (3) treatment duration, (4) patient, demographic characteristics, and (5) practitioner demographic and practice characteristics.

Treatment was ascertained on the basis of the T1 and T2 questionnaires, with the latter enquiring about any changes in the treatment plan that were implemented after the enrollment time. In cases in which there were inconsistencies in reported treatment, clinical records were reviewed to confirm treatment.

Four mutually exclusive treatment categories were identified for investigation: (1) ALNs with no FA, TADs, or SX; (2) FA with no TADs, or SX; (3) TAD with no SX; and (4) orthognathic surgery (SX).

The treatment groups represent an increasing ability to manage complex malocclusions and an increasing level of invasiveness. Patients with treatment from multiple categories were categorized into the more invasive treatment category. For example, a patient treated with both aligners and FA was placed in the FA group. Almost all patients in the TADs or SX groups also underwent FA. Extractions of a premolar or anterior teeth were also identified, which could be performed in combination with any of the treatment groups listed above.

Patient T1 dentofacial characteristics were reported at enrollment, and cephalometric values were obtained from T1 cephalograms. Dentofacial characteristics identified for examination included profile, molar classification, maxillary and mandibular crowding, posterior crossbite, facial pattern, habits, and missing teeth. T1 cephalometric values evaluated included: ANB (°), mandibular plane angle (Mp-SN) (°), IMPA (°), and overbite (mm).

The duration of active orthodontic treatment was calculated as the time from appliance placement to appliance removal, on the basis of information from the T1 and T2 questionnaires, respectively. Patient characteristics included age, gender, race, insurance coverage, education level, and previous orthodontic treatment. Practitioner characteristics included,

Table I. Practitioner demographics

	n	%
Status		
Orthodontist	82	98
General practitioner	2	2
Sex		
Male	61	73
Female	23	27
Age, y		
<45	32	38
45-54	24	29
55-64	23	27
≥65	5	6
Race and ethnicity, n = 83		
White	52	63
Asian	19	23
Multiracial	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

Note. n = 84, unless indicated otherwise.

specialization, country of dental school, age when enrolled in dental network, gender, race and ethnicity, years since graduation from dental school, geographic region of practice, and practice type.

Descriptive statistics were performed on the patient and practitioner sample.

Overall success rates were calculated on the basis of the following outcome measures: (1) positive overbite (mm) on T2 lateral cephalogram, and (2) T2 POSI = 0—indicating positive overlap of all anterior teeth.

Because the cephalometric overbite measurements were only based on the most anterior central incisors, the POSI—which assesses the vertical position of all incisors—was used in most analyses.

Success rates for treatment modality, patient T1 dentofacial characteristics and cephalometric measures, treatment duration, patient demographic characteristics, and practitioner demographic and practice characteristics were obtained. Bivariate analyses were preliminarily performed to identify factors with statistically significant differences in treatment success. The clustering of patients within practitioners was adjusted for by using a generalized estimating equation. This clustering was implemented using PROC GENMOD in SAS (version 9.4, SAS Institute Inc, Cary, NC) with the CORR = EXCH option.

Multivariable predictive models were developed to identify predictors for treatment success, defined as POSI = 0. Specifically, the differences between success rates for different treatment categories (ie, SX vs no SX, SX vs FA, TADs vs FA, ALN vs FA) were explored. The predictive models were developed by entering all variables with $P < 0.10$ after adjusting for the clustering of patients within practices. Backward 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 the significance level because of clinical importance. SAS software was used to perform all statistical analyses.

Table II. Patient demographics

	n	%
Sex, n = 253		
Male	64	25
Female	189	75
Age, y, n = 253		
18-20	43	17
21-30	106	42
31-40	58	23
≥41	46	18
Race and ethnicity, n = 253		
White	146	58
Black	23	9
Asian	24	9
Multiracial	8	3
Hispanic	52	21
Previous orthodontic treatment, n = 253		
Yes	106	42
No	147	58
Insurance coverage, n = 254		
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's degree	84	33
Graduate degree	45	18

RESULTS

A total of 91 practitioners and 347 patients and were recruited for this study from October 2015 to June 2016. Data on T2 were collected from 84 practitioners and 260 patients through December 2018. Six patients had insufficient data for analyses, leaving a total of 254. The

Table III. T1 and T2 POSI scores

		POSI at T2						
POSI at T1	*No. of patients*	*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

Note. Missing = 22.

Table IV. Treatment summary

			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
			POSI at T2 = 0	
Treatment duration (months)	n	%	n = 190	%
<17	52	23	45	86
17-22	52	23	44	85
23-29	70	31	63	90
>30	54	24	38	70

remainder of the practitioners and patients either withdrew from the study (24) or did not complete treatment within the study period (63). In addition, 24 patients were missing T2 cephalometric data, leaving a total of 230 patients for cephalometric analysis. Patients missing T2 intraoral images (22) 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 (standard deviation [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 I and II.

The mean T1 overbite measured from the lateral cephalograms was −2.3 mm (SD, 2.1; range, −12.9 mm to 1.1 mm). All patients did not have a vertical overlap of at least 1 incisor (POSI >0), and no incisors had contact with opposing teeth. Sixty-five percent (n = 151) exhibited no vertical overlap of all 4 incisors (POSI ≥4).

The mean T2 overbite measured from the lateral cephalograms was 1.3 mm (SD, 1.1 mm; range, −5.6 mm to 3.7 mm). Ninety-three percent of patients (n = 215) had a positive overbite measured on the T2 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). A summary of T1 and T2 POSI scores are presented in Table III. Two-thirds of our sample was classified as having a long-faced skeletal pattern on the basis of the vertical morphologic classification system.[19]

Eleven percent of patients were treated with aligners only, 60% with FA only (no TADs or SX), 8% with TADs (no SX), and 21% with SX. Most of the TAD and SX patients also underwent FA therapy. Despite a recommendation rate of 37% for SX, only 21% of patients who completed treatment had surgery.[20] Treatment is summarized in Table IV.

Patients in the TADs and surgery treatment groups exhibited slightly higher success rates compared with those treated with aligners or with FA only, but these differences were not statistically significant when comparing all 4 groups in a single model (Table V).

Table V. Treatment modality and extractions vs treatment success

	All	*POSI = 0*			*Extractions*	*POSI = 0*			*No extractions*	*POSI = 0*		
	n = 232	*n = 194*	%	P	*n = 45*	*n = 34*	%	P	*n = 187*	*n = 160*	%	P
Final treatment category*				0.3				NE				0.4
Aligners only	26	21	81		0	0	Undefined		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	46	42	91		5	5	100		41	37	90	
Extractions				0.2								
No	187	160	86									
Yes	45	34	76									
				OR = 0.5								

Note. Percentages are, namely, the proportion of the "outcome" treatment (column heading) for that treatment comparison. *P* values are adjusted for the clustering of patients within practitioners using generalized estimating equations.
NE, Not estimable.
*Missing n = 22.

Nineteen percent of patients had extractions of anterior or premolar teeth for orthodontic treatment. Extractions were most common in the FA treatment group. No patients treated with aligners had extractions. Only 3 patients treated with TADs and 5 patients treated with surgery had extractions. Although nonextraction patients had a 10% greater success than those treated with extractions (86% vs 76%), this difference did not reach statistical significance (Table V).

T1 dentofacial characteristics were evaluated for differences in treatment success. The results are summarized in Table VI. Initial crowding was the only characteristic with significance in the bivariate analysis. Success rates were about 17% higher in patients with less crowding.

Patient T1 cephalometric values were evaluated for differences in rates of treatment success. Steeper mandibular planes displayed a trend to be associated with less treatment success ($P = 0.07$). There was no difference in success rates on the basis of the magnitude of T1 overbite when evaluated as either a categorical or continuous variable. Success rates ranged from 81% to 85% on the basis of the initial overbite measurements.

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. However, success rates were higher in patients with a shorter treatment duration. Patients with treatment durations <30 months were 17% more successful than those with treatment >30 months (70% vs 87%, $P = 0.02$) (Table IV).

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 VII).

Practitioner characteristics were examined for differences in treatment success. The practice type was the only variable with significant differences in treatment success (Table VIII). Patients treated by practitioners in an academic setting had the highest success rate (98%), whereas 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 nonacademic settings (odds ratio [OR], 10.5; $P = 0.005$). Forty-two of the 43 patients treated in an academic setting had successful closures of their open bite (Table IX). It is important to note the greater percentage of patients treated with surgery and TADs in academic settings compared with other practice settings.

Multivariable models were used to predict treatment success. Four separate models were developed to compare treatment groups (FA vs ALN, TAD vs FA, SX vs FA, and SX vs no SX). The results from these predictive models are summarized in Table X. The full models include all variables that had $P < 0.1$, as well as 3 variables that were included in all models because of their clinical importance (treatment category, extractions, and initial overbite in mm). The reduced models only included the 3 variables mentioned above, as well as any variables that retained statistical significance. Academic practice setting was not included in the final model because only 1 patient had unsuccessful treatment. However, it should be stressed that treatment at academic centers was associated with the highest success rates.

The predictive model of treatment success comparing FA to aligners had 2 significant variables. Patients with no to mild T1 crowding (OR, 2.9; $P = 0.03$) and patients with shorter treatment durations (<30 months) (OR, 3.0;

Table VI. Patient T1 dentofacial characteristics and cephalometric values vs treatment success

Patient dentofacial characteristics	*All* *n* = 232	*POSI = 0* *n* = 194	Percentage, %	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 (1-3 mm)	94	85	90	
Moderate crowding (4-6 mm)	71	52	73	
Severe crowding (>6 mm)	23	17	74	
Posterior crossbite				0.8
None	137	116	85	
Unilateral	46	37	80	
Bilateral	49	41	84	
POSI				0.6
1-3	81	69	85	
4-6	151	125	83	
Cephalometric values				
ANB (°)*				0.3
<0	31	28	90	
0-4	111	95	86	
>4	84	65	77	
Mp-SN (°)†				0.07
≤30	24	23	96	
>30-34	37	32	86	
>34-38	50	41	82	
>38	114	91	80	
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
Mandibular incisor angulation, IMPA (°)*				0.2
≤86	37	29	78	
>86-90	25	21	84	
>90-94	44	38	86	
>94-98	42	39	93	
>98	78	61	78	
Total	186			

Note. Percentages are, namely, the proportion of the "outcome" treatment (column heading) for that treatment comparison. *P* values are adjusted for the clustering of patients within practitioners using generalized estimating equations.
*Missing n = 6; †Missing n = 7; ‡Missing n = 5.

P = 0.04) were more likely to have a successful treatment result.

In a model comparing TADs to FA only, treatment modality did not have a significant effect on success. The only variable that had a significantly higher level of success was T1 Mp-SN <30° (OR, 4.1; *P* = 0.046).

The predictive model comparing surgery to FA had 2 significant factors. Surgical treatment was associated with higher success (OR, 2.6; *P* = 0.04), and those with no to mild T1 crowding (OR = 2.5; *P* = 0.04) also had higher levels of success.

In a model comparing surgical patients to all other patients, 3 factors were significant. Patients with no to mild T1 crowding (OR, 2.6; *P* = 0.02), those whose treatment duration was less than 30 months (OR, 2.6; *P* = 0.04), and those with a T1 Mp-SN <30° (OR, 4.1;

Table VII. Patient demographic characteristics vs treatment success

Patient demographics	All	POSI = 0		P
	n = 232	n = 194	Row, %	
Sex				0.9
Male	57	48	84	
Female	174	145	83	
Age, y				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	137	114	83	
Black/African American	18	16	89	
Asian	22	19	86	
Multiracial, 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's degree	77	66	86	
Graduate degree	40	34	85	
Previous orthodontic treatment				0.15
No	136	118	87	
Yes	95	75	79	

Note. Percentages are, namely, the proportion of the "outcome" treatment (column heading) for that treatment comparison. *P* values are adjusted for the clustering of patients within practitioners using generalized estimating equations.

$P = 0.04$) had higher levels of success. Surgical treatment was associated with a trend toward more successful treatment (OR, 2.2; $P = 0.10$).

DISCUSSION

This study shows very high success rates for orthodontically treated adult patients with AOB in the United States. At the end of treatment, 84% of the patients had a positive vertical overlap of all 4 incisors, and 93% had positive overbite as measured using the central incisors on the T2 lateral cephalogram. Given the complexity and challenges commonly associated with the treatment of patients with AOB, these success rates are encouraging. However, experienced practitioners know the challenge will be the successful retention of these treatment results in the coming years.

Although the small number of patients in the TAD and aligner groups hampered statistical analyses, there were some interesting findings on treatment modality. The success rates for patients treated with aligners and FA were the same (81%). This result is consistent with findings from a retrospective study by Garnett et al,[11] who reported no differences in the magnitude of open bite and associated cephalometric changes between patients treated with FA vs clear aligners. The success rates in patients treated with TADs (89%) and orthognathic surgery (91%) were also similar. Kuroda et al[7] found similar magnitudes of overbite correction when comparing patients treated with TADs and orthognathic surgery. 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, along with the closure of the mandibular plane.[21] With TADs, the intrusion of both maxillary and mandibular molars is possible, and with surgery, impaction of the posterior maxilla effectively raises the vertical position of the molars.[22,23]

In the final models—which adjust for T1 characteristics and other influencing factors—orthognathic surgery was the only treatment modality found to have a statistically significant higher rate of treatment success compared with FA only. These findings are consistent with a systematic review published in 2011, reporting slightly higher treatment success and stability for surgical treatment of AOB malocclusions.[16]

Table VIII. 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	
Sex				0.5
Male	172	145	84	
Female	60	49	82	
Race and ethnicity				0.6
White	141	120	85	
Asian	64	53	83	
Hispanic	22	19	86	
Other/unknown	5	2	40	
Age, y				0.6
<45	92	74	80	
45-54	55	49	89	
55-64	71	60	84	
≥65	14	11	79	
Years since dental degree				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, nonsolo 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	

Note. Percentages are, namely, the proportion of the "outcome" treatment (column heading) for that treatment comparison. *P* values are adjusted for the clustering of patients within practitioners using generalized estimating equations.
NE, Not estimable.

In some cases, extractions are recommended for AOB treatment. Our results showed no significant difference in treatment success between patients treated with and without extractions. The absolute success rates were lower in extraction patients. Janson et al[12] showed no difference, but a similar trend, in final overbite measures for patients treated with and without extractions (1.09 mm vs 1.43 mm, respectively). In our sample, extractions were typically reserved for patients with severe crowding and increased mandibular incisor proclination.[20] In these patients, 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.

Although patient and practitioner demographic characteristics were not significant predictors of treatment success in our sample, the 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 result may also be explained by the high clinical standards that accompany teaching institutions.

The predictive models for treatment success identified 3 additional variables that exhibited statistically significant relationships to treatment success: T1 Mp-SN, T1 crowding, and treatment duration.

Table IX. Academic and nonacademic practice settings vs treatment success

Practice setting	*All* *n* = 231	*POSI* = 0 *n* = 193	%	P	
Academic practice					
Yes	43	42	98	0.005	OR = 10.4
No	188	151	80		
Primary treatment rendered					
Academic practices	n = 43	n = 42			
Aligners only	4	4	100	NE	
Fixed, no TADs or surgery	17	17	100		
TADs, no surgery	9	8	89		
Surgery	13	13	100		
Nonacademic practices	n = 188	n = 151			
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		

Note. Percentages are, namely, the proportion of the "outcome" treatment (column heading) for that treatment comparison. *P* values are adjusted for the clustering of patients within practitioners using generalized estimating equations.
NE, not estimable.

Table X. Multivariable predictive models* for treatment success (pairwise comparisons) defined as POSI = 0 at T2

Fixed vs aligners (n = 167 [141 vs 26])†	*OR*	P	*TADs vs fixed (n = 160 [19 vs 141])*†	*OR*	P
Full			Full		
Fixed vs aligners	1.3	0.6	TADs vs fixed	1.6	0.5
Extract	0.8	0.7	Extract	0.6	0.4
No/mild crowding	2.7	0.04	No/mild crowding	2.1	0.13
Tx duration <30 mo	2.9	0.038	Tx duration <30 months	2.1	0.15
Mp-SN (Base: <30°)	3.4	0.14	Mp-SN (Base: <30°)	3.3	0.13
OB, mm (Base: continuous)	1.1	0.2	OB, mm (Base: continuous)	1.1	0.4
Reduced			Reduced		
Fixed vs aligners	1.3	0.6	TADs vs fixed	1.6	0.5
Extract	0.8	0.7	Extract	0.5	0.2
No/mild crowding	2.9	0.027	Mp-SN (Base: <30°)	4.1	0.046
Tx duration <30 mo	3.0	0.036	OB, mm (Base: continuous)	1.1	0.3
OB, mm (Base: continuous)	1.1	0.3			
Surgery vs fixed (n = 187 [46 vs 141])†	*OR*	*P*	*Surgery vs no surgery (n = 232 [46 vs 186])*†	*OR*	*P*
Full			Full		
Surgery vs fixed	2.4	0.07	Surgery vs no surgery	2.2	0.10
Extract	0.9	0.8	Extract	0.8	0.7
No/mild crowding	2.3	0.06	No/mild crowding	2.6	0.02
Tx duration <30 mo	2.1	0.2	Tx duration <30 mo	2.6	0.035
Mp-SN (Base: <30°)	3.1	0.16	Mp-SN (Base: <30°)	4.1	0.039
OB, mm (Base: continuous)	1.1	0.2	OB, mm (Base: continuous)	1.1	0.3
Reduced			Reduced		
Surgery vs fixed	2.6	0.04	No change - all retained		
Extract	0.8	0.7			
No/mild crowding	2.5	0.04			
OB, mm (Base: continuous)	1.2	0.2			

Tx, Treatment; *OB,* overbite.
*Treatment comparison of interest, whether extraction of tooth other than the third molar was performed, and baseline open bite measurement (OB, mm) are included in models regardless of statistical significance. All characteristics with *P* <0.1 when adjusted only for the clustering of patients within the practice are entered in the full model. Characteristics are removed until all remaining have *P* <0.1, with exceptions noted; †Numbers used in each model; numbers in brackets are for treatment comparison of interest.

Patients with T1 Mp-SN less than 30° had a greater chance for treatment success than those with steeper Mp-SN. It is possible that patients with lower Mp-SN had open bites that were more dental. In contrast, patients with steeper Mp-SN may have had open bites that were more skeletal. It is interesting to note that the mean Mp-SN was highest in the patients who were recommended orthognathic surgery. However, although the surgery was recommended to 37% of our subjects, only 21% of the patients who provided end-of-treatment data had undergone surgery.

T1 crowding was a significant variable in 3 predictive models for treatment success. Ninety-four patients were categorized as having moderate to severe crowding, but only 45 subjects underwent extractions other than third molars. Thus, almost half of the patients with moderate to severe crowding were treated nonextraction. Typically, resolution of moderate to severe crowding when no extractions are performed will result in forward tipping of the incisors, which is associated with further worsening of the open bite. Patients with no crowding or mild crowding would be less affected by this issue.

Treatment duration was also found to be a significant predictor of success in patients treated with FA and patients treated with aligners. Patients with a treatment duration of less than 30 months had a 15%-20% higher rate of treatment success. This result 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 may also reflect changes to treatment plans or patients' expectations when treatment is not progressing as expected. 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 FA. This finding 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 aligner therapy does, which is a large contributing factor to the length of treatment.

AOBs of greater magnitude are considered more challenging malocclusions to treat and are often thought of as being associated with lower success rates. Interestingly, initial AOB severity, classified by T1 cephalometric overbite, was not a significant predictor of treatment success in any of the final models. Several factors might have influenced this finding. First, it is possible that practitioners particularly interested and skilled in open bite treatment enrolled in the study, and their clinical expertise resulted in high success rates, regardless of the initial severity. Similarly, practitioners were not limited to 1 specific treatment modality and could recommend the treatment they thought was most appropriate. Surgery was recommended to 37% of the subjects. Thus, it is possible that more robust techniques were appropriately recommended to patients with more severe open bites. Another factor may have been the effect of participating in a study, which may have influenced the practitioner's attention to the case, as well as the patient's cooperation with treatment. Finally, practitioners were allowed to change treatment plans, and if treatment was not progressing well with 1 treatment, additional treatments could be recommended. We plan to evaluate whether the severity of the initial overbite may be a factor if we only look at 1 treatment modality (eg, FA only). In addition, it will be interesting to assess the relationship between initial severity and stability in the follow-up stage of the study.

There were several limitations to our study. The patient and practitioner sample was not randomly selected. 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 demographically similar to the American Association of Orthodontists' membership. Practitioners were asked to enroll all patients who met the study's inclusion criteria to minimize patient selection bias. Another limitation was that the treatment was not randomized. Practitioners selected the method of treatment for each patient. This approach 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 ALN and TAD groups reduced the power of our statistical analyses. The treatment timeline constraints may have resulted in a biased patient sample consisting of fewer unsuccessfully treated patients. T2 data were not received from 93 subjects who either submitted incomplete data ($n = 6$), withdrew from the study ($n = 24$), or did not complete treatment in the study period ($n = 63$). The patients who did not complete treatment may have been more difficult cases with a lower chance for success. However, baseline characteristics of patients with T2 data ($n = 254$) and patients missing the T2 data ($n = 93$) were compared. There was no difference in mean T1 overbite or recommended treatment modality. Although not statistically significant, there was a trend of higher POSI scores for patients missing the T2 data. There was a significant difference in the estimated treatment time, with patients completing treatment having shorter estimated treatment times (Supplementary Table). An additional source of bias could arise from preferential levels of treatment being provided to patients that practitioners judged to be more likely to have favorable outcomes. Although we do not have any evidence that practitioners displayed this type of bias, we have no way to assess this.

CONCLUSIONS

Overall success rates were very high for adult patients receiving orthodontic treatment for AOB malocclusions. Although 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 or practitioner demographics and treatment success. Several T1 dentofacial characteristics, including T1 Mp-SN and amount of crowding, academic practice setting, and treatment duration, were significant predictors of treatment success in adult patients with AOB.

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SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ajodo.2020.07.033.

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