The National Dental Practice-Based Research Network Adult Anterior Open Bite Study: Treatment recommendations and their association with patient and practitioner characteristics

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Introduction: This aim of this paper is to describe and identify the practitioner and patient characteristics that are associated with treatment recommendations for adult anterior open bite patients across the United States. **Methods:** Practitioners and patients were recruited within the framework of the National Dental Practice-Based Research Network. Practitioners were asked about their demographic characteristics and their treatment recommendations for these patients. The practitioners also reported on their patients' dentofacial characteristics and provided initial cephalometric scans and intraoral photographs. Patients were asked about their demographic characteristics, previous orthodontic treatment, and goals for treatment. Four main treatment groups were evaluated: aligners, fixed appliances, temporary anchorage devices (TADs), and orthognathic surgery. Extractions were also investigated. Predictive multivariable models were created comparing various categories of treatment as well as extraction/nonextraction decisions. **Results:** Ninety-one practitioners (mostly orthodontists) and 347 patients were recruited from October 2015 to December 2016. Increased aligner recommendations were associated with white and Asian patients, the presence of tongue habits, and female practitioners. TADs were recommended more often in academic settings. Recommendations for orthognathic surgery were associated with demographic factors, such as availability of insurance coverage and practitioner race/ethnicity, and dentofacial characteristics, such as anteroposterior discrepancies, more severe open bites, and steeper mandibular plane angles. Extraction recommendations were largely associated with severe crowding and incisor proclination. **Conclusions:** Both doctor and patient demographic factors, as well as dentofacial characteristics, were significantly associated with treatment recommendations for adult anterior open bite patients. (Am J Orthod Dentofacial Orthop 2019;156:312-25)

The prevalence of anterior open bite (AOB) in the United States ranges from 0.6% to 16.5%, varying by age and ethnic group.[1] Despite the relatively low overall prevalence of open bite, it is a condition that prompts many affected individuals to seek treatment, as evidenced by estimates that as many as 17% of patients

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All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
Funding: National Institute of Dental and Craniofacial Research grant U19-DE-22516. Opinions and assertions contained herein are those of the authors and are not to be construed as necessarily representing the views of the respective organizations or the National Institutes of Health.
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Submitted, February 2019; revised and accepted, May 2019.
0889-5406/$36.00

https://doi.org/10.1016/j.ajodo.2019.05.005

with skeletal discrepancies present with anterior open bites.[2] The etiology of anterior open bite may be straightforward, such as a digit habit, or multifactorial, related to skeletal, respiratory, and neuromuscular factors.[3,4]

Numerous treatment modalities have been proposed to address anterior open bite malocclusion, including habit devices,[5] myofunctional therapy,[6] conventional fixed appliances, extraction of teeth,[7] clear aligners,[8] temporary anchorage devices (TADs),[9] occlusal equilibration,[10] and orthognathic surgery.[11] Traditionally, treatments such as habit appliances and fixed appliances have been recommended to children and adolescents, while orthognathic surgery has often been recommended to adults, especially when the open bites are moderate to severe. However, clear aligners and TADs have emerged as alternate techniques to address open-bite malocclusions, and case reports indicate that they may be successful even in moderate to severe cases.[8,12]

To date, there have been no studies that evaluate treatment recommendations for AOB malocclusions in adults. Although a patient's dentofacial characteristics may play the largest role in an orthodontist's treatment recommendations, other factors may also influence treatment recommendations. For example, do treatment recommendations for open bite patients vary depending on the age or experience of the practitioner? Do patient demographics, such as age and insurance coverage, play a role? Ultimately, practitioners would like to know what factors play the largest roles in treatment recommendations and whether these factors are based on valid evidence and successful outcomes.

In 2015, the present study was launched within the National Dental Practice-Based Research Network.[13] The overall study aims were to investigate orthodontic recommendations, patient acceptance of treatment recommendations, treatment success, posttreatment stability, and patient satisfaction related to treatment of adult patients with AOB. A previous publication described the demographic characteristics of the practitioners and patients enrolled in the study.[14] The present paper reports on the first aim of the study, specifically, to identify and describe what practitioner and patient characteristics are associated with treatment recommendations in adults with AOB.

MATERIAL AND METHODS

Providers recruited for this study were from the 6 geographic regions (West, Midwest, Southwest, South Central, South Atlantic, and Northeast) of the National Dental Practice-Based Research Network. Institutional Review Board (IRB) approval was obtained from institutions representing the regions: University of Alabama IRB (acting as the Central IRB), Kaiser Permanente Northwest IRB (for the Western region), and University of Rochester Research Subjects Review Board (for the Northeast region). Practitioners completed an enrollment questionnaire when joining the network, which collected information on the practitioners and their practices. Additional questionnaires completed by practitioners and patients at enrollment provided patient demographic information, dentofacial characteristics of the patients, and details related to treatment. For each patient, practitioners were requested to list their most recommended plan up to two additional plans offered to the patient. All study forms can be accessed at http://nationaldentalpbrn.org/anterior-open bite-malocclusions-in-adults-recommendations-treatment-and-stability.php.

Informed consents of all human subjects who participated in this investigation were obtained after the nature of the procedures had been explained fully. An internet site devoted to details about the network is located at http://NationalDentalPBRN.org.

The inclusion criteria for practitioners were as follows: orthodontist or dentist who routinely performs orthodontic treatment; estimates that they can 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; routinely takes cephalometric radiographs (cephalograms) before and after treatment; has the ability to upload (via internet) deidentified cephalometric radiographs and digital intraoral frontal photographs to a central repository; affirms that the practice can devote sufficient time in patient scheduling to allow focused recording of all data required for the study; and does not anticipate retiring, selling the practice, or moving during the study.

For patients, the inclusion criteria were: at least 18 years of age at time of enrollment; has AOB defined as 1 or more incisors that do not have vertical overlap with teeth in the opposing arch; the remaining incisors may have minimal incisor overlap, but none of them can contact teeth in the opposing arch (determined by examining the patient's initial cephalogram, intraoral photographs, or initial plaster or digital casts); in active treatment for AOB and expected to have treatment completed within 24 months of enrollment into the study; and has an initial cephalogram (taken before the beginning of treatment); a cephalogram created from a cone-beam computed tomographic scan was acceptable.

Recruitment was restricted to adults to eliminate the influence of growth on treatment outcome. In addition, to avoid selection bias, practitioners were requested to enroll all eligible patients. Practitioner and patient

Fig. The photographic open bite severity index (POSI) has 6 categories, based on the type and number of teeth that do not have vertical overlap. It was developed to score the relative severity of the patients' open bites with the use of the intraoral frontal photographs.

questionnaires were sent to regional centers where they were reviewed for completeness and entered into a centralized database, with range and logic checks. The statistician provided the study principal investigator with data outliers to review for clinical "reasonableness/validity." Questionable values were sent to regional coordinators to review for accuracy of data entry, and subsequent review of clinical records was conducted as needed.

Along with the questionnaires, pretreatment cephalometric radiographs and frontal intraoral digital photographs were collected and sent electronically to a central site. The radiographs were imported into Dolphin imaging software (Patterson Dental, Saint Paul, Minn), and custom cephalometric analyses were performed, which have been previously described.[1]

Data analysis

Practitioner characteristics evaluated included specialization (orthodontist or general dentist), country of dental school, gender, age, race and Hispanic/Latino ethnicity, years in dental practice, geographic region of practice, and practice type.

Patient characteristics included demographics (sex, age, race and Hispanic/Latino ethnicity, insurance coverage, and level of education) and previous orthodontic experience. Dentofacial characteristics included profile, molar classification, arch length discrepancy, the presence or absence of posterior crossbite, and habits. In addition, the following cephalometric characteristics were evaluated: ANB angle, mandibular plane angle, posterior facial height (PFH), upper and lower incisor angulation, overbite (OB), and overjet (OJ).

An index was developed to score the relative severity of the patients' open bite with the use of the intraoral frontal photographs. The photographic open bite severity index (POSI) has 6 categories, based on the type and number of teeth that do not have vertical overlap (Fig). The categories are: 1 = 1 or 2 maxillary (MX) lateral incisors without vertical overlap (but both MX central incisors have vertical overlap); 2 = 1 MX central incisor without vertical overlap (the other MX central has vertical overlap); 3 = 2 MX central incisors without vertical overlap (at least one MX lateral has vertical overlap); 4 = All 4 MX incisors without vertical overlap; 5 = All anterior teeth without overlap (canine to canine); and 6 = category 5 plus at least 1 premolar without vertical overlap.

Cephalometric images from 10 patients were randomly selected to measure inter- and intrarater reliability by 2 investigators. They identified each identified landmark from which 24 measurements were

automatically calculated and then 4 weeks later repeated the procedure. Both inter- and intrarater reliability were excellent as determined with the use of intraclass correlations. The mean interrater reliability was 97% (range 91% to 99%) and the mean intrarater reliability was 98% (range 95% to 99%). For the POSI, 20 frontal intraoral images were rated twice, 1 month apart. The interrater mean agreement was 92.5% and the mean kappa 95.5%. The intrarater mean agreement was 97% and the mean kappa 98.5%.

Treatment recommendations were divided into 4 mutually exclusive categories: (1) ALN: aligners (patients recommended fixed appliances, TADs, or orthognathic surgery were excluded); (2) FA: fixed appliances (patients could also have been recommended aligners, but patients recommended TADs or orthognathic surgery were excluded); (3) TAD (patients could also have been recommended aligners and/or fixed appliances, but patients recommended orthognathic surgery were excluded); and (4) SX: orthognathic surgery (patients could also have been recommended aligners, fixed appliances, and TADs).

In general, these treatment modalities indicate an increasing ability to manage more complex malocclusions, as well as an increasing level of invasiveness. When patients were recommended combinations of appliances, for example, aligners and fixed appliances, or fixed appliances with TADs, they were placed into the most invasive treatment category. Because extractions are sometimes used as a strategy for open bite closure, factors associated with recommendations for extractions were also investigated.

Frequencies of treatment recommendations were first obtained according to the 4 treatment categories of primary interest. Patients were also categorized based on previous orthodontic treatment, missing teeth, and recommendations for tooth extraction. Then the frequencies of practitioner characteristics, patient demographic and dentofacial characteristics, and the POSI were obtained according to the 4 recommended treatment categories. Descriptive statistics (eg, means, standard deviations) of cephalometric measures and patient age were performed.

Because of clustering of patients within practitioners, all statistical significance was assessed by entering each practitioner/patient characteristic into a logistic regression model that used a generalized estimating equations method that adjusted for clustering of patients within the practice. This was implemented with the use of PROC GENMOD in SAS with the CORR = EXCH option.

Predictive models were developed to investigate the 4 categories of treatment recommendations. Specifically, the differences between recommendations for adjacent treatment categories (ALN vs FA, FA vs TAD, and TAD vs SX) and for orthognathic surgery versus the other 3 categories combined (ALN, FA, and TAD) were assessed. The multivariable predictive models were built by entering all of the characteristics with $P < 0.10$, and using backward elimination until all characteristics had $P < 0.10$, except for orthognathic surgery versus other 3 treatment groups, which used $P < 0.05$. This was done because of the small number of patients in the ALN and TAD treatment categories. Extractions and previous orthodontic treatment were included in the initial model building for the treatment recommendations, but they were removed if they did not attain and retain significance. Supplementary Tables I-IV (available at www.ajodo.org) present practitioner, patient demographic, dentofacial, and cephalometric associations for each of the treatment comparisons.

Separate predictive models were also developed for extraction recommendations, as extractions are sometimes performed to allow a drawbridge effect (the overbite deepens as the incisors are uprighted during retraction).[15] In these models, patients were excluded from analyses if they were already missing four premolars, because they would not likely be candidates for additional extractions. In addition, extraction patients were defined as patients who were referred for extraction of anterior teeth or premolars, because those would be the most common strategies to address crowding or open bite closure. Patients who had only third molar removal recommendations were not classified as extraction patients. (We performed sensitivity analyses in which patients who had only third molars recommended for extraction were classified as extraction patients. Because the results did not differ from our initial model, we present only the results using our extraction model as described above.) All analyses were performed with the use of SAS software (v9.4; SAS Institute, Cary, NC).

RESULTS

A total of 91 practitioners were recruited from October 2015 through June 2016, almost all of them orthodontists. These practitioners exhibited a large age span, with a mean age of 49 years (SD 10). Eighty-six percent attended dental school in the United States and the mean number of years since graduating was 22 (SD 10). The practitioners were primarily white (62%) and Asian (24%). Twenty-six percent were female, and 75% were in private practice. Twelve percent practiced in academic settings.

From October 2015 to December 2016, 358 patients were enrolled. Eleven did not meet the inclusion

Table I. Distribution of 345 patients according to ideal treatment category, prior orthodontic treatment, or missing teeth

	Overall		Previous orthodontic treatment (n = 134)		Missing teeth			
					Any (n = 201)		Any tooth other than third molar (n = 74)	
Variable	*n*	*%*	*n*	*Row %*	*n*	*Row %*	*n*	*Row %*
Treatment category*								
Aligners	35	10	18	51	23	66	6	17
Fixed appliances†	146	42	45	31	72	49	34	23
Temporary anchorage devices‡	35	10	20	57	23	66	9	26
Orthognathic surgery§	129	37	51	40	83	64	25	19
Cluster-adjusted *P* value‖			0.02		0.03		0.7	
Previous orthodontic treatment								
No	210	61			112	53	45	21
Yes	134	39			88	66	29	22
Cluster-adjusted *P* value‖					0.12		0.99	

*Two patients were not recommended any of the 4 primary treatments of interest and were therefore excluded from analysis.
†Includes 4 with aligners.
‡Includes 6 with aligners without fixed appliances; 33 were miniscrews and 2 were miniplates.
§Includes 7 with aligners and no fixed appliances, 2 with aligners and fixed appliances, 118 with only fixed appliances, and 2 with fixed appliances and TAD miniscrews.
‖*P* values adjusted for patient clustering within practitioner by means of generalized estimating equations.

criterion of pretreatment open bite, leaving 347 patients. The mean pretreatment overbite measured on lateral cephalograms was −2.4 mm. More than 66% of the patients fell into POSI categories 4, 5, or 6, indicating that they had no vertical overlap of all 4 incisors. In some analyses, we collapsed the POSI categories into 1-3 versus 4-6. The mean age of the enrolled patients was 31.4 years old, and 74% were female. Additional information about enrolled practitioners and patients has been previously reported.[14]

For 150 patients, practitioners reported offering only 1 treatment recommendation, for 130 patients 2 options were provided, and 67 patients were provided with 3 treatment options. For the analyses, the first recommendation for the patient was used, because it represented what the practitioner thought would be the most ideal treatment for the patient. A total of 345 patients were recommended 1 of the 4 main treatments: 35 (10%) ALN, 146 (42%) FA, 35 (10%) TAD, and 129 (37%) SX. A total of 134 patients (39%) reported previous orthodontic treatment (Table I).

At least 1 tooth was missing in 201 patients (58%), a majority of whom were missing only third molars (63%; n = 127). Of the 74 patients who were missing other teeth, 7 were missing incisors, 5 canines, 39 premolars, and 37 first or second molars. Only 14 patients were missing 4 premolars, leaving 331 patients in our analyses of extraction recommendations.

Due to the very low number of patients (~1%) from general dentists, no analyses were performed separately for their recommendations. It was interesting to note that 1 general dentist recommended TADs to multiple patients.

In descriptive analyses, female practitioners were 3 times more likely than males to recommend ALN therapy to correct anterior open bite (20% vs 7%). White and Asian orthodontists were more likely to recommend SX treatment than orthodontists of other races/ethnicities (41% vs 11%). Older practitioners tended to recommend more ALN and less TAD therapy. Practitioners in academic settings recommended more TAD therapy. ALN was recommended to 12%-18% of patients in the West, Southwest, and Northeast regions, whereas ALN was not recommended as the ideal treatment to any patients in the other 3 regions (Table II).

The majority of the patients were female (74%), white (55%), and had some form of dental or medical insurance (78%). In descriptive analyses, male patients received slightly higher percentages of TAD and SX recommendations. White patients received more SX recommendations than patients of other races/ethnicities. Insurance coverage for orthognathic surgery was a major factor, with 68% of patients receiving an SX recommendation if they had insurance that covered orthognathic surgery and 26% receiving an SX recommendation if they did not have coverage. A trend

Table II. Practitioner/practice characteristics according to most ideal treatment recommendation category

			Treatment category*								Cluster-adjusted P value†			
	All (n = 345)		Aligners only (n = 35)		Fixed appliances (n = 146)		Temporary anchorage devices (n = 35)		Orthognathic surgery (n = 129)					
Practitioner characteristics	n	%	n	Row %	n	Row %	n	Row %	n	Row %	ALN vs FA	FA vs TAD	TAD vs SX	SX: yes vs no
Specialty											NE	NE	NE	NE
General practice	3	1	0	0	0	0	3	100	0	0				
Orthodontist	342	99	35	10	146	43	32	9	129	38				
Country trained in											0.99	0.9	0.4	0.98
United States	279	81	28	10	124	44	24	9	103	37				
Other	66	19	7	11	22	33	11	17	26	39				
Gender											0.06	0.16	0.4	0.7
Male	254	74	17	7	112	44	27	11	98	39				
Female	91	26	18	20	34	37	8	9	31	34				
Race/ethnicity											NE	NE	NE	0.007
White	200	58	13	7	73	37	20	10	94	47				
Asian	101	29	13	13	44	44	14	14	30	30				
Hispanic/Latino	38	11	9	24	24	63	1	3	4	11				
Other/unknown	6	2	0	0	5	83	0	0	1	17				
Age (years)											0.8	0.8	0.12	0.06
<45	134	39	13	10	70	52	14	10	37	28				
45-54	78	23	10	13	20	26	13	17	35	45				
55-64	110	32	3	3	51	46	7	6	49	45				
≥65	23	7	9	39	5	22	1	4	8	35				
Years since dental degree											0.9	0.7	0.08	0.13
<10	37	11	3	8	23	62	4	11	7	19				
10-19	129	37	12	9	56	43	15	12	46	36				
20-29	85	25	8	9	26	31	12	14	39	46				
≥30	93	27	12	13	41	44	4	4	36	39				
Type of practice											0.4	NE	NE	0.4
Solo, private practice	154	45	15	10	56	36	17	11	66	43				
Owner, nonsolo private	72	21	8	11	37	51	3	4	24	33				
Associate in private practice	35	10	7	20	21	60	3	9	4	11				
Preferred provider	15	4	1	7	8	53	0	0	6	40				
Academic	64	19	4	6	22	34	12	19	26	41				
Region											NE	NE	NE	0.6
Western	161	47	20	12	55	34	19	12	67	42				
Midwest	33	10	0	0	17	52	2	6	14	42				
Southwest	38	11	7	18	10	26	6	16	15	39				
South Central	20	6	0	0	10	50	0	0	10	50				
South Atlantic	38	11	0	0	23	61	5	13	10	26				
Northeast	55	16	8	15	31	56	3	5	13	24				

ALN, Aligners only; *FA*, fixed appliances; *NE*, not estimable; *SX*, orthognathic surgery; *TAD*, temporary anchorage device.
*Treatment categories are mutually exclusive (see Table I); 2 practitioners were excluded because none of the 4 primary treatments were recommended.
†*P* values adjusted for patient clustering within practitioner by means of generalized estimating equations.

was observed that clear aligner therapy was recommended more often to patients with higher levels of education. ALN therapy and TADs were about 2 times more likely to be recommended to patients who had undergone previous orthodontic treatment (Table III).

A majority of patients had a convex profile (54%), no posterior crossbite (58%), a high-angle facial pattern (59%), and POSI score 4-6 (68%). About one-third had mild (35%) or moderate (31%) crowding in either the maxillary or the mandibular arch. Class I malocclusions were present in 41% of the patients, Class II in 31%, and Class III in 28%.

In descriptive analyses, the severity of molar relationship had a positive influence on the recommendations

Table III. Patient demographics and previous orthodontic treatment according to most ideal treatment recommendation category

			Treatment category*								Cluster-adjusted P value†			
	All (n = 345)		Aligners only (n = 35)		Fixed appliances (n = 146)		Temporary anchorage devices (n = 35)		Orthognathic surgery (n = 129)					
Characteristic	n	%	n	Row %	n	Row %	n	Row %	n	Row %	ALN vs FA	FA vs TAD	TAD vs SX	SX: yes vs no
Patient demographics														
Sex											0.6	0.06	0.6	0.4
Male	91	26	10	11	32	35	12	13	37	41				
Female	253	74	25	10	113	45	23	9	92	36				
Age (years)											0.6	NE	0.2	0.4
18-20	57	17	4	7	21	37	5	9	27	47				
21-30	155	45	15	10	67	43	15	10	58	37				
31-40	76	22	10	13	35	46	10	13	21	28				
≥41	56	16	6	11	22	39	5	9	23	41				
Mean (SD)	31.4	11.2	33.7	12.6	30.9	10.3	32	10.7	30.9	12.1				
Race/ethnicity											NE	NE	0.7	0.04
White	188	55	19	10	54	29	23	12	92	49				
Black	34	10	0	0	23	68	2	6	9	26				
Asian	29	8	5	17	14	48	3	10	7	24				
Multiple, other	12	4	0	0	5	42	3	25	4	33				
Hispanic/Latino	78	23	11	14	47	60	3	4	17	22				
Dental or medical insurance											NE	0.9	0.02	<0.001
None	78	22	7	9	39	50	14	18	18	23				
Yes, orthodontics and SX not covered	87	25	12	14	39	45	8	9	28	32				
Yes, orthodontics covered, SX not covered	93	27	16	17	45	48	8	9	24	26				
Yes, SX covered[6]	87	25	0	0	23	26	5	6	59	68				
Education level											0.07	NE	0.8	0.9
High school/GED or less	71	21	7	10	32	45	7	10	25	35				
Some college/AD	109	32	5	5	51	48	12	11	41	38				
Bachelor degree	105	31	14	13	40	38	9	9	42	40				
Graduate degree	57	17	9	16	20	35	7	12	21	37				
Less than bachelor degree	180	53	12	7	83	46	19	11	66	37	0.07	0.4	0.98	0.8
Bachelor degree or higher	162	47	23	14	60	37	16	10	63	39				
Previous orthodontic treatment														
No	210	61	17	8	101	48	15	7	77	37	0.06	0.9	0.07	0.6
Yes	134	39	18	13	45	34	20	15	51	38				

ALN, Aligners only; *FA*, fixed appliances; *NE*, not estimable; *SX*, orthognathic surgery; *TAD*, temporary anchorage device.
*Treatment categories are mutually exclusive (see Table I); 2 patients were excluded because none of the 4 primary treatments were recommended.
†*P* values adjusted for patient clustering within practitioner by means of generalized estimating equations.

for surgery. SX was recommended to 58% of patients with greater than half-cusp Class II molar relationship and to 40% of patients with more than half-cusp Class III molar relationship, compared with 21% of the patients who were Class I or within a half-cusp of Class I. The presence of posterior crossbite was also a factor in SX recommendations. SX was recommended to 24% of patients with no posterior crossbite, 47% of patients with unilateral posterior crossbite, and 63% of patients with bilateral posterior crossbite. High-angle facial patterns also were associated with higher percentages of SX recommendations, compared with normal or short facial patterns. There were no clear relationships between tongue or thumb habits and recommendations for treatment, but ALN seemed to be recommended more often to patients with tongue thrusting or posture habits. SX was recommended to 22% of the patients who were in POSI categories 1-3,

Table IV. Patient dentofacial characteristics according to most ideal treatment recommendation category

			Treatment category*								Cluster-adjusted P value†			
	All (n = 345)		Aligners only (n = 35)		Fixed appliances (n = 146)		Temporary anchorage devices (n = 35)		Orthognathic surgery (n = 129)					
Characteristic	n	%	n	Row %	n	Row %	n	Row %	n	Row %	ALN vs FA	FA vs TAD	TAD vs SX	SX: yes vs no
Profile											0.3	NE	0.2	0.3
Convex	187	54	19	10	76	41	18	10	74	40				
Straight	129	37	15	12	56	43	16	12	42	33				
Concave	29	8	1	3	14	48	1	3	13	45				
Molar class (severest of right/left)											0.8	0.3	0.13	<0.001
I: up to half cusp Class II or Class III	142	41	22	15	75	53	15	11	30	21				
II: Half cusp or more Class II	106	31	7	7	26	24	12	11	61	58				
III: Half cusp or more Class III	95	28	6	6	43	45	8	8	38	40				
Arch length (severest of maxillary or mandibular)											0.2	NE	NE	0.5
No crowding	70	20	7	10	31	44	8	11	24	34				
Mild crowding (1-3 mm)	122	35	15	12	47	39	16	13	44	36				
Moderate crowding (4-6 mm)	106	31	7	7	45	42	11	10	43	41				
Severe crowding (>6 mm)	47	14	6	13	23	49	0	0	18	38				
Posterior crossbiite											0.7	0.4	0.008	<0.001
None	201	58	25	12	105	52	22	11	49	24				
Unilateral	68	20	7	10	21	31	8	12	32	47				
Bilateral	76	22	3	4	20	26	5	7	48	63				
Facial pattern											0.2	0.8	0.09	<0.001
High angle	202	59	21	10	64	32	20	10	97	48				
Normal	123	36	13	11	69	56	13	11	28	23				
Low angle	19	6	1	5	13	68	2	11	3	16				
Tongue thrust											0.2	0.09	0.8	0.2
No	237	69	20	8	97	41	25	11	95	40				
Yes	108	31	15	14	49	45	10	9	34	31				
Tongue posture											0.03	0.4	0.2	0.3
No	261	74	21	8	115	44	24	9	101	39				
Yes	84	26	14	17	31	37	11	13	28	33				
Digit											0.10	NE	0.6	0.5
No	319	92	32	10	132	41	34	11	121	38				
Yes	26	8	3	12	14	54	1	4	8	31				
Function/biting/bruxing											0.4	0.4	0.2	0.5
No	330	96	32	10	144	44	32	10	122	37				
Yes	15	4	3	20	2	13	3	20	7	47				
AOB severity index											0.7	0.8	0.03	<0.001
1-3	111	32	10	9	61	55	15	14	25	22				
4-6	234	68	25	11	85	36	20	9	104	44				

AOB, Anterior open bite; *ALN*, aligners only; *FA*, fixed appliances; *NE*, not estimable; *SX*, orthognathic surgery; *TAD*, temporary anchorage device.
*Treatment categories are mutually exclusive (see Table I); 2 patients were excluded because none of the 4 primary treatments were recommended.
†*P* values adjusted for patient clustering within practitioner by means of generalized estimating equations.

whereas it was recommended to 44% of patients who were in categories 4-6 (Table IV).

Consistent with the vertical pattern of the face, patients with larger mandibular plane angles had higher recommendations for SX; the mean mandibular plane angle was 41.5° for surgical patients and 37.2° for nonsurgical patients. Also, larger open bites were associated with higher rates of SX recommendations. Patients with recommendations for FA tended to have the most proclined incisors (Table V).

Ninety patients were recommended to have at least 1 tooth extracted. Of these, 23 were recommended only third molar removal. In the remaining 67 patients, 61 were recommended premolar extractions, and 6 were recommended removal of anterior teeth. Thirty-four of the premolar extraction recommendations were for 4

Table V. Cephalographic measures according to most ideal treatment recommendation category

Mean cephalographic measures

			Treatment category[*]								
	All (n = 345)		*Aligners only (n = 35; 10%)*		*Fixed appliances (n = 146; 42%)*		*Temporary anchorage devices (n = 35; 10%)*		*Orthognathic surgery (n = 129; 37%)*		
Measure	*Mean*	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*	*Cluster-adjusted P value*[†]
ANB: maxilla to mandible	3.2	(3.1)	3.5	(3.0)	3.2	(2.8)	2.9	(2.6)	3.4	(3.6)	0.5
MPSN: mandibular plane angle	38.8	(7.2)	38.9	(7.4)	36.6	(6.5)	38.1	(7.7)	41.5	(7.0)	<0.001
PFH mm: posterior facial height	46.2	(6.0)	45.1	(4.8)	47.2	(6.3)	47.2	(4.8)	45.3	(6.0)	0.11
U1 degree	25.6	(8.3)	25.3	(7.6)	27.5	(8.4)	24.2	(8.0)	24.0	(8.1)	0.052
L1 degree	31.1	(8.3)	30.8	(6.4)	33.4	(8.5)	27.6	(6.9)	29.6	(8.3)	0.004
IMPA (MN incisor angulation to MP)	94.9	(8.8)	95.3	(6.6)	98.2	(8.4)	92.5	(7.8)	91.7	(8.6)	<0.001
Overbite (mm)	−2.4	(2.2)	−2.1	(1.6)	−2.2	(2.0)	−1.5	(1.8)	−3.0	(2.4)	0.009
Overjet (mm)	3.2	(2.7)	3.6	(2.0)	3.1	(2.5)	3.4	(2.0)	3.2	(3.2)	0.9

Associations of cephalometric measures with most ideal treatment recommendation category

	Cluster-adjusted odds ratio (ORs) and P value[†]							
	ALN vs FA		*FA vs TAD*		*TAD vs SX*		*SX: yes vs no*	
Measure	*OR*	P	*OR*	P	*OR*	P	*OR*	P
ANB: maxilla to mandible	0.97	0.7	1.05	0.3	0.96	0.4	1.02	0.6
MPSN: mandibular plane angle	1.02	0.3	0.96	0.2	0.93	0.03[‡]	1.09	<0.001[‡]
PFH mm: posterior facial height	0.96	0.2	1.02	0.4	1.06	0.09[‡]	0.96	0.06[‡]
U1 degree	0.98	0.5	1.05	0.01[‡]	1.00	0.99	0.96	0.02[‡]
L1 degree	0.96	0.07[‡]	1.12	<0.001[‡]	0.97	0.3	0.97	0.04[‡]
IMPA (MN incisor angulation to MP)	0.97	0.16	1.11	0.002[‡]	1.01	0.6	0.93	<0.001[‡]
Overbite (mm)	1.12	0.3	0.80	0.015[‡]	1.46	<0.001[‡]	0.82	<0.001[‡]
Overjet (mm)	1.01	0.9	1.00	0.98	1.01	0.8	0.98	0.7

ALN, Aligners only; *FA*, fixed appliances; *NE*, not estimable; *SX*, orthognathic surgery; *TAD*, temporary anchorage device.
[*]Treatment categories are mutually exclusive (see Table I); 2 patients were excluded because none of the 4 primary treatments were recommended.
[†]Adjusted for patient clustering within practitioner by means of generalized estimating equations.
[‡]$P < 0.10$.

premolars. Extractions were much less frequent in patients recommended for ALN therapy (only 2 of 35 ALN patients [6%] had recommendations for nonmolar extractions, compared to 9%-30% in the other treatment categories). Patients who reported previous orthodontic treatment were also less likely to be recommended extractions (Table VI).

No specific practitioner characteristics were associated with extraction recommendations (Supplementary Table I). Regarding patient demographics, extractions were more commonly recommended to younger patients and to those who had no previous orthodontic treatment (Supplementary Table II). Several patient dentofacial characteristics were associated with increased extraction recommendations, especially increased crowding (Supplementary Table III), convex profiles, and the absence of tongue thrust habits and bruxing. Cephalometrically, increased ANB angles, mandibular plane angles, and mandibular incisor proclination were related to more extraction recommendations (Supplementary Table IV).

Predictive models

To account for potentially confounding variables, we developed multivariable predictive models for the main treatment recommendations as well as extractions (Table VII).

The predictive model for patients recommended ALN versus FA had only 2 significant factors. White and Asian patients were recommended ALN almost 3 times as often as black or Hispanic/Latino patients. In addition, patients with tongue posture habits were 2.4 times more likely to be recommended ALN over FA. Although female practitioners recommended ALN more than 3

Table VI. Distribution of 345 patients according to their most ideal treatment recommendation category and whether extractions were recommended

		Recommend extractions						
				Nonmolar				
	All (n = 345)	Any (n = 90)		All (n = 67)		Exclude 14 patients missing 4 premolars (n = 331)		
Variable	n	n	Row %	n	Row %	All	n	Row %
Main treatment category*								
Aligners	35	3	9	2	6	35	2	6
Fixed appliances	146	53	36	44	30	139	44	32
Temporary anchorage devices	35	7	20	3	9	31	3	10
Orthognathic surgery	129	27	21	18	14	126	18	14
Cluster-adjusted *P* value†		0.01		0.003			0.004	
Previous orthodontic treatment								
No	210	70	33	53	25	208	53	25
Yes	134	20	15	14	10	122	14	11
Cluster-adjusted *P* value†		0.002		0.006			0.01	

*Two patients were excluded because none of the 4 primary treatments were recommended.
†*P* values adjusted for patient clustering within practitioner by means of generalized estimating equations.

times as often as male practitioners in the final model, the *P* value was slightly greater than 0.05.

The prediction model for FA versus TAD included 4 variables with $P < 0.10$. Practitioners from private practice settings were much less likely to recommend TAD than practitioners in academic settings (odds ratio [OR] 0.2; $P = 0.03$). For each additional degree of upper and lower incisor proclination, FA alone was about 5%-10% more likely to be recommended than FA with TAD. Also, black and Hispanic/Latino patients were more than 3 times less likely to receive recommendations for TAD compared with white or Asian patients.

The strongest predictor for a SX recommendation over TAD was the availability of insurance coverage for orthognathic surgery. A second predictor for surgical recommendations was having a Class II or Class III malocclusion in conjunction with AOB. Finally, each millimeter of additional open bite severity was associated with 1.4 times greater odds of receiving an SX recommendation than one for TAD.

When a prediction model was developed for orthognathic surgery versus any other kind of less invasive treatment, several factors were identified. In decreasing impact, they were the race/ethnicity of the practitioner (OR 5.8), the availability of insurance coverage for SX (OR 3.8), the presence of posterior crossbite (OR 3.6), A-P molar discrepancies (OR 3.4), less severe overbite (OR 0.87 for every mm), and increased mandibular plane angle (OR 1.09 for every degree).

A predictive model was developed for extractions, excluding patients missing 4 premolars. We found that increased age and presence of tongue habits were associated with fewer extraction recommendations, and severe crowding and increased mandibular incisor proclination were associated with more extraction recommendations. Of these, severe crowding had by far the greatest impact, with an OR of 8.

DISCUSSION

This paper provides a snapshot of treatment recommendations made by U.S. practitioners (almost all being orthodontic specialists) for their adult open bite patients from October 2015 to December 2016. Eighty-five percent of the 88 orthodontists were in private practice settings. They largely reflected the American Association of Orthodontists (AAO) membership in terms of gender, age, race, Hispanic/Latino ethnicity, practice location, and experience.[16] The exception was a higher percentage of academicians in our sample compared with AAO membership as a whole.

The categorization of treatment into 4 major groups was done to investigate the rationale behind treatment recommendations. Obviously, health care providers should attempt to recommend the most appropriate treatments based on each patient's condition. Although some patient characteristics were significantly associated with treatment recommendations, there were other factors unrelated to the patient's malocclusion that also were significantly associated with treatment recommendations.

The predictive models for the 4 main types of treatment are the most important findings from our

Table VII. Multivariable predictive models for treatment and extraction recommendations

	Individual		*Final model*		
Characteristic	*OR*	P	*OR*	*95% CI*	P
Recommending aligners vs fixed appliances (no TAD or SX): 35 vs 142 (total of 177; excludes 4 patients recommended aligners and braces)					
Practitioner female	3.6	0.059	3.5	1.1-11.3	0.058
Patient white or Asian vs black or Hispanic/Latino	2.8	0.006	2.8	1.5-5.2	0.009
Patient education: BS or higher	1.5	0.07	x	x	x
Previous orthodontic treatment	1.8	0.06	x	x	x
Habit: tongue posture	2.5	0.03	2.4	1.2-4.6	0.04
L1 degree	0.96	0.07	x	x	x
Recommend extraction	0.4	0.02	x	x	x
Recommending fixed appliances alone vs fixed appliances and TAD (no SX): 146 vs 29 (total of 175)					
Academic practice	0.2	0.01	0.2	0.06-0.95	0.03
Patient black or Hispanic/Latino	4.8	0.001	3.6	1.4-8.9	0.02
Previous orthodontic treatment	0.3	0.007	x	x	x
Habit: digit	5.0	0.01	x	x	x
U1 degree	1.05	0.01	1.05	1.00-1.10	0.03
L1 degree	1.12	<0.001	1.10	1.03-1.17	0.003
L1MP degree	1.11	0.002	x	x	x
Overbite (mm)	0.80	0.016	x	x	x
Recommend extraction	4.8	0.01	x	x	x
Recommending TADs vs orthognathic surgery: 35 vs 127 (total of 162; excludes 2 patients recommended TAD and SX)					
No insurance coverage for SX	3.4	0.02	2.7	1.2-6.5	0.046
Previous orthodontic treatment	2.0	0.07	x	x	x
Molar Class 1 (vs 2 or 3)	2.2	0.045	2.4	1.1-5.1	0.061
No posterior crossbite	3.5	0.002	2.2	1.0-5.0	0.054
Normal or low-angle facial pattern	2.9	0.03	2.2	1.0-4.6	0.099
AOB score 4-6 (vs 1-3)	0.3	0.3	x	x	x
MPSN (mandibular plane angle)	0.93	0.03	x	x	x
PFH mm	1.06	0.09	x	x	x
Overbite (mm)	1.47	<0.001	1.4	1.1-1.8	<0.001
Recommending orthognathic surgery (yes vs no): 127 vs 216 (total of 343; excludes 2 patients recommended TAD and SX)					
DDS white or Asian	4.3	0.02	5.8	1.7-20.1	0.02
Patient white	2.5	0.002	x	x	x
Insurance covers SX	4.8	<0.001	3.8	1.9-7.9	<0.001
Molar Class 2 or 3	3.3	<0.001	3.4	1.8-6.1	<0.001
Any posterior crossbite	3.9	<0.001	3.6	2.1-6.3	<0.001
Steep facial angle	4.1	<0.001	x	x	x
AOB score 4-6 vs 1-3	3.1	<0.001	x	x	x
MPSN (mandibular plane angle)	1.10	<0.001	1.09	1.04-1.14	<0.001
U1 degree	0.96	0.02	x	x	x
L1 degree	0.97	0.04	x	x	x
L1MP degree	0.93	<0.001	x	x	x
Overbite (mm)	0.82	<0.001	0.87	0.76-0.99	0.04
Recommending extractions of nonmolars: 67 vs 264 (total of 331; excludes 14 patients missing 4 premolars)					
Patient age (y)	0.97	0.03	0.96	0.93-0.99	0.01
Prior orthodontic treatment	0.44	0.01	x	x	x
Convex profile	2.4	0.008	x	x	x
Moderate/severe crowding	5.1	<0.001	8.0	4.3-14.8	<0.001
No/unilateral posterior crossbite vs bilateral	2.6	0.02	x	x	x
Tongue posture	0.39	0.01	0.40	0.17-0.96	0.02
ANB: maxilla to mandible	1.13	0.01	x	x	x
MPSN (mandibular plane angle)	1.04	0.03	x	x	x
L1 degree	1.05	0.007	1.09	1.05-1.13	<0.001

OR, odds ratio; *x*, characteristic was not lower than either 10% or 5%, depending on comparisons, and therefore was not retained in the model; *AOB*, anterior open bite; *ALN*, aligners only; *FA*, fixed appliances; *NE*, not estimable; *SX*, orthognathic surgery; *TAD*, temporary anchorage device. All associations (OR) and *P* values are adjusted for clustering of patients within practices by means of generalized estimating equations. They were implemented using PROC GENMOD in SAS. Individual column ORs and *P* values are adjusted only for clustering of patients within practitioners.

analyses. These models allowed us to compare recommendations while accounting for potentially confounding factors. Specifically, the orthognathic surgery/no-surgery decision may be of most interest, owing to the invasiveness and risks of surgery. Although more severe dentofacial characteristics were associated with SX recommendations, there were several other factors related to higher SX recommendations. These included practitioners who were white or Asian and the availability of insurance coverage for orthognathic surgery. In fact, the race/ethnicity of the practitioner was associated with the highest odds of receiving a surgical recommendation (OR 5.8), and the impact of insurance coverage on a surgical recommendation (OR 3.8) was similar to the highest dentofacial characteristics (posterior crossbite: OR 3.6; Class II or Class III malocclusion: OR 3.4). This model indicates that a practitioner's own preference for SX, as well as their perception of a patient's acceptance and ability to afford the procedure, may play a major role in surgical recommendations. Although these recommendation biases may exist, it may be more important to know how dentofacial characteristics affect treatment success, which we plan to investigate.

Our ability to create a predictive model for ALN versus FA was hampered by the small number of patients who received recommendations for ALN. Only 2 factors, white or Asian race/ethnicity, compared with other races/ethnicities, and the presence of a tongue habit, exhibited statistically significant relationships with ALN recommendations. Although the percentage of extraction patients was lower in patients with ALN recommendations (only 2 of the 35 ALN patients were recommended non–third molar extractions) this relationship was not significant in the final model. The higher rate of recommendations for ALN in patients with tongue habits is interesting, because no studies could be found reporting the use of ALN to address tongue habits. Perhaps this relationship is due to the reluctance to extract teeth in patients with tongue habits, but we did control for extraction in our model building. The absence of ALN recommendations to any patients in 3 out of our 6 regions was surprising and may have been related to preferences of the practitioners or patients in those regions.

When comparing FA with TAD in a multivariable predictive model, 4 variables exhibited statistical significance. Clearly, in our sample, receiving treatment in an academic setting predisposed patients to TAD recommendations. This may be explained by the teaching mission of academic centers, and the need for faculty and students to become familiar with these techniques. Interestingly, the degree of open bite or the steepness of the mandibular plane were not associated with TAD recommendations, which might indicate that practitioners do not yet agree on the indications where TAD may be a useful adjunct to FA. Similarly to the situation with ALN, white and Asian patients received more TAD recommendations. The decreased recommendations for TAD when incisors were more proclined was not expected, because TADs could provide additional anchorage for retraction.

When comparing TAD and SX, the lack of insurance coverage for surgical treatment was significantly associated with an increased likelihood of a TAD recommendation by almost 3 times. Class I malocclusions and less severe open bites were also associated with more TAD recommendations. A recent systematic review indicated that posterior intrusion with the use of TADs is possible, resulting in mandibular autorotation.[17] This effect is similar to maxillary impaction surgery, without the invasiveness of orthognathic surgery.[11] Therefore, it was hypothesized that the characteristics for patients receiving recommendations for TAD and SX would be similar. In fact, the variable most strongly associated with TAD recommendations was the absence of insurance coverage for orthognathic surgery, which may indicate that the use of TADs is a viable alternative when surgery is not available. Regarding molar classification, TAD seems to be recommended more when there was no concomitant A-P skeletal discrepancy. Also, for each additional millimeter of open bite severity, the odds of an SX recommendation versus a TAD recommendation increased by 40%.

There were several other interesting findings regarding clear aligners and TADs. In a previous paper looking at practitioners' general strategies for open bite treatment, 33% indicated that they used aligners frequently and 48% occasionally.[14] However, in the present sample of 347 patients, only about 10% of the patients were recommended aligners as a first option. Similarly, 12% of practitioners self-reported frequent use of TADs for open bite and 62% occasionally, but in the present sample TADs were recommended to only 10% of the patients as part of the most ideal plan. Thus, although practitioners may self-report relatively high adoption of these 2 techniques, they may not yet recommend them as the most ideal option. In addition, although we might predict higher use of ALN in mild open bites and higher use of TAD in severe open bites, these patterns were not observed. This may indicate that practitioners are still exploring the best indications for these techniques in adult open bite patients. Because aligners and TADs are less invasive than orthognathic surgery, they are appealing to practitioners and patients,

especially if open bites can be predictably closed and exhibit good stability.

Regarding extractions, they were largely not performed unless crowding was moderate to severe. Although the potential for a drawbridge effect can assist in open bite closure, practitioners may be less inclined to perform extractions unless there is significant crowding or protrusion, owing to the tendency for open bite patients to have forward tongue posture. A recent systematic review indicates that extraction patients tended to have more severe pretreatment open bites, and about 1 mm more of absolute open bite closure at the end of treatment, providing some support for this effect.[18]

A limitation of the present study is that the sample of practitioners was not random or consecutively chosen. Practitioners volunteered to participate, and it is possible these practitioners may have a special interest in open bite malocclusions and, likely, specific treatment preferences. However, as previously mentioned, the demographic composition of our practitioners was very similar to that of AAO members, with the exception that our study included more practitioners from academic settings. Likewise, patients were not randomly chosen, but we did ask the practitioners to consecutively enroll every patient who met the inclusion criteria.

A clustering effect is well established in studies that first recruit practitioners and then patients.[19] Practitioners were able to enroll up to 15 patients, and there could be treatment and proficiency biases. For example, 1 practitioner submitted 14 cases, 11 of whom were treated with clear aligners. One clinician submitted 3 cases, all of whom were treated with TADs. Adjustment for clustering was performed in the analyses, but residual effects could remain.

Another significant limitation was the small number of patients who received TAD and ALN recommendations (only 35 in each group), as well as the number of independent variables that were assessed for all treatment options. Even with combining some independent variable categories (eg, practitioner/practice characteristics, patient demographics, and dentofacial characteristics), there were some predictor-outcome combinations with no patients, thereby precluding modeling of those relationships. This is well illustrated in the case of ALN recommendations, because in 3 of the 6 regions ALN was not recommended to any patients. Clearly a difference in recommendation patterns exists, but not one that could be modeled. Again, some caution must be employed in interpreting the analyses involving the aligner and TAD groups, owing to the small number of practitioners and patients.

CONCLUSIONS

The primary treatment recommendations for 4 major categories of orthodontic treatment were investigated. Increased ALN recommendations were associated with white and Asian patients, the presence of tongue habits, and female practitioners. TAD was recommended more often when patients were seen in academic settings. SX recommendations were associated with both demographic factors (availability of insurance, white and Asian practitioners) and dentofacial characteristics (transverse or A-P discrepancies, larger open bites, and steeper mandibular plane angles). Recommendations for extractions were largely associated with severe crowding and to a lesser degree with proclined incisors.

ACKNOWLEDGMENTS

The authors gratefully acknowledge all of the practitioners and patients who made this study possible. They are also grateful to the National Dental Practice-Based Research Network's regional coordinators: Sarah Basile, RDH, MPH, Chris Enstad, BS, and Hannah Van Lith, BA (Midwest); Stephanie Hodge, MA, and Kim Stewart (Western); Pat Ragusa (Northeast); Deborah McEdward, RDH, BS, CCRP, and Danny Johnson (South Atlantic); Claudia Carcelén, MPH, Shermetria Massingale, MPH, CHES, and Ellen Sowell, BA (South Central); and Stephanie Reyes, BA, Meredith Buchberg, MPH, and Monica Castillo, BA (Southwest). The authors also thank Kavya Vellala and the Westat Coordinating Center staff, the American Association of Orthodontists (AAO), Jackie Hittner (AAO Librarian), Gregg Gilbert, DDS, MBA (National Dental Practice-Based Research Network Director), and Dena Fischer, DDS, MSD, MS (National Institute of Dental and Craniofacial Research Program Director).

SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajodo.2019.05.005.

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