AJO-DO

Influence of overjet and overbite on soft tissue profile in mature adults: A cross-sectional population study

Georgios Kanavakis,[a] Laura Krooks,[b] Raija Lähdesmäki,[c] and Pertti Pirttiniemi[c]
Basel, Switzerland, Boston, Mass, and Oulu, Finland

Introduction: The aim of this study was to explore the association of soft tissue profile and severity of overbite and overjet in a large adult population. **Methods:** The study population consisted of 1630 adults (age, 46 years; 712 men, 919 women), all part of the Northern Finland Birth Cohort 1966. A clinical examination was performed on all subjects, including recording of overjet and overbite, and digital facial (frontal and profile) photographs were obtained. A multivariate regression model was developed to study the correlation of soft tissue measurements with overjet and overbite, considering the effect of sex. **Results:** The regression model explained approximately 30% of the variability in overjet in our sample and approximately 22% of the variability in overbite. Overjet was related more significantly to upper and lower anteroposterior lip position, and upper and lower facial height ($P < 0.05$). Overbite showed a stronger association with anteroposterior position of the lower lip, pogonion, and soft tissue B-point ($P < 0.05$). **Conclusions:** Soft tissue profile was weakly to moderately correlated with severity of overjet and overbite in the entire sample. However, in subjects with negative overjet (mandibular prognathism), this association was highly significant. (Am J Orthod Dentofacial Orthop 2019;155:57-63)

In orthodontics, great emphasis is placed on the potential for creating facial change by correcting malocclusion. This agrees with patients' primary motivation to undergo orthodontic treatment: ie, facial esthetics.[1-4] Historically, the criteria for achieving optimal facial esthetics have been changing to adapt to societal perceptions,[5] and orthodontists have always played an important role by applying these criteria to their treatment planning. Technological advances in imaging,[6] photography,[7] and intraoral scanning[8] provide great opportunities for studying patients' characteristics more accurately, and even allow clinicians to make soft tissue predictions with varying degrees of accuracy.[9]

Inarguably, dental malocclusion has a significant impact on facial soft tissue characteristics,[10-12] which in turn have an impact on facial and smile appearance. Particularly, overjet and anterior open bite have been shown to strongly influence the position of the upper lip and the dimension of the lower face, respectively.[11,12]

In addition to cephalometric methods[13-15] and to overcome their inherent limitations,[16] alternative methods to study facial soft tissues from frontal and profile photographs have also been proposed.[10,11,17] Despite their restrictions related to patient position and standardization of obtaining the images, photographs are a noninvasive alternative tool that can be potentially useful in day-to-day clinical diagnosis and treatment planning.[18]

Most orthodontic patients are adolescents; hence, the impact of orthodontic treatment on facial soft tissues will be additive to any natural changes. After the

[a]Department of Orthodontics and Pediatric Dentistry, Universitäres Zentrum für Zahnmedizin Basel University School of Dental Medicine, University of Basel, Basel, Switzerland; Research Unit of Oral Health Sciences, Medical Faculty, University of Oulu, Oulu, Finland; Department of Orthodontics and Dentofacial Orthopedics, School of Dental Medicine, Tufts University, Boston, Mass.
[b]Research Unit of Oral Health Sciences, Medical Faculty, University of Oulu, Oulu, Finland.
[c]Research Unit of Oral Health Sciences, Medical Faculty, University of Oulu, Oulu, Finland; Medical Research Center, Oulu University Hospital, Oulu, Finland.
All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
Georgios Kanavakis and Laura Krooks are joint first authors and contributed equally to this work.
The Northern Finland Birth Cohort 1966 received financial support from the University of Oulu (grant number 24000692), the Oulu University Hospital (grant number 24301140), and the European Regional Development Fund (grant number 539/2010 A31592). Laura Krooks received research funding from the Finnish Dental Society Apollonia and the Finnish Women Dentist Association.
Address correspondence to: Georgios Kanavakis, Department of Orthodontics and Pediatric Dentistry, UZB-University School of Dental Medicine, University of Basel, 3 Hebelstrasse, 4056 Basel, Switzerland; e-mail, georgios.kanavakis@unibas.ch.
Submitted, September 2017; revised and accepted, February 2018.
0889-5406/$36.00

https://doi.org/10.1016/j.ajodo.2018.02.015

growth of the underlying dentoalveolar structures, the upper lip increases in length and thickness in both sexes until the age of approximately 15 years, with boys experiencing greater overall changes.[19-21] In adulthood, both sexes have a gradual increase in nose length as well as a reduction in lip thickness and an overall flattening of the profile.[22,23] Facial flattening is more pronounced in men due to a greater increase in chin prominence compared with women.[23] This information raises the question of how anterior occlusion affects the facial appearance of adults. There are few previous cephalometric studies regarding the correlation between malocclusion and facial profile in adults, and those that do exist have limited study samples and heterogeneous cohorts.[24] Therefore, the aim of this investigation was to explore the association between overjet, overbite, and soft tissue profile characteristics in a large, homogenous group of middle-aged subjects. The study will provide valuable information concerning the effect of malocclusion on the facial appearance of mature adults and place the long-term impact of orthodontic treatment into a broader social perspective.

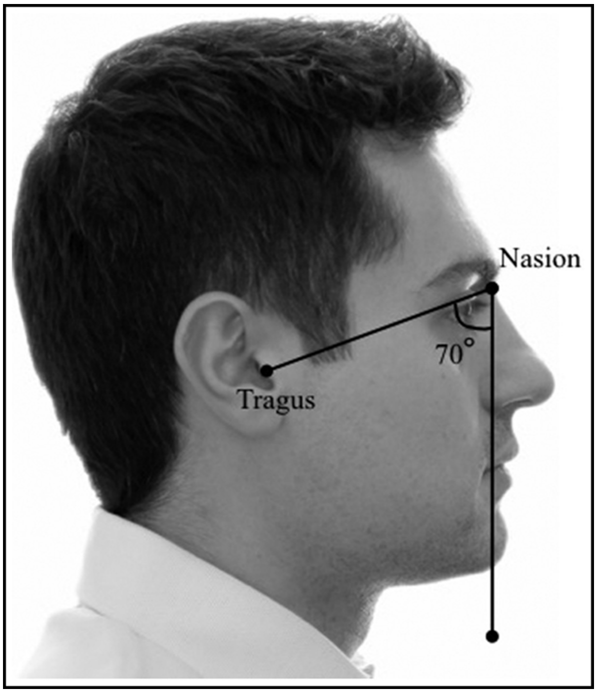


Fig 1. Vertical reference line.

MATERIAL AND METHODS

The study population for this investigation was part of the Northern Finland Birth Cohort 1966, an epidemiologic and longitudinal research program aiming to promote the health and well-being of the population in northern Finland. It comprises 12,058 people who were born in 1966 in the 2 northernmost provinces of Finland, Oulu and Lapland, and represents 96.3% of all births in this region in this year.[25]

The initial population for this study consisted of 1964 persons (912 men, 1052 women) who volunteered to participate in follow-up clinical examinations in 2012. To be included in the study, participants had to have full records from the clinical examination, clinical photographs of diagnostic quality, and intraoral 3-dimensional scans and orthopantomograms. Subjects with craniofacial syndromes or severe facial deformities were not included. After applying these criteria, the final study population consisted of 1630 participants (711 men, 919 women). The study was approved by the ethical committee of the Northern Ostrobothnia Hospital District in September 2011, and written consent was obtained from all volunteers before their participation.

Less than 20% of the study population had undergone previous orthodontic treatment. All participants had a standardized clinical examination, including intraoral occlusal measurements, bite registration, and clinical photographs. A detailed description of the subjects' medical and dental histories and their clinical oral examinations, including measurements of overjet and overbite, can be found in previously published material.[26] Clinical photographs were obtained in a standardized manner. One profile and 2 frontal photographs (resting and posed smiling) were taken of each participant (600D, EF-S 60 mm, f/2.8 Macro USM, general illumination; Canon, Melville, NY). A mark on the floor was used to determine where subjects had to stand to have their picture taken. The camera was fixed on a tripod at 190 cm from the mark where the participants stood. Camera settings were fixed to f/5.6 and ISO/200 (jpeg-format).

Profile photographs were uploaded to ViewBox software (dHAL Software, Kifissia, Greece), and the following soft tissue landmarks were identified by 1 examiner (L.K.).

1. Glabella: the most prominent point of the forehead as it appears on a profile picture.
2. Nasion: the deepest point of the curvature between glabella and the bridge of the nose.
3. Pronasale: the most prominent point of the nose on the horizontal axis.
4. Subnasale: the deepest point of the curvature connecting the nose to the upper lip.
5. FA point of the upper lip: the most prominent (anterior) point of the upper lip.
6. A-point: the deepest point of the curvature between subnasale and FA point of the upper lip.

Table I. Linear and angular measurements for assessment of facial profile

A-point–B-point to tragus	*The distance from A-point to tragus line minus the distance from B-point to tragus line*
Upper lip to tragus line	The distance between the FA point of the upper lip and tragus line
Lower lip to tragus line	The distance between the FA point of the lower lip and tragus line
Pogonion to tragus line	The distance between pogonion and tragus line
Convexity subnasale	The angle between the lines connecting glabella-subnasale-pogonion
Tragus pogonion to tragus-subnasale (%)	The ratio of the linear distances between tragus-pogonion and tragus-subnasale
Tragus-nasion to tragus-subnasale (%)	The ratio of the linear distances between tragus-nasion and tragus-subnasale
Tragus–A-point to tragus-subnasale (%)	The ratio of the linear distances between tragus–A-point and tragus-subnasale
Tragus–B-point to tragus-subnasale (%)	The ratio of the linear distances between tragus–B-point and tragus-subnasale
Lower facial height (%)	The ratio of the distances between subnasale-menton (lower facial height) and nasion-menton (full facial height)
Upper facial height (%)	The ratio of the distances between nasion-subnasale (lower facial height) and nasion-menton (full facial height)

7. FA point of the lower lip: the most prominent (anterior) point of the lower lip.
8. Pogonion: the most prominent (anterior) point of the chin.
9. B-point: the deepest point of the curvature between pogonion and FA point of the lower lip.
10. Gnathion: the most anterior-inferior point of the chin.
11. Menton: the most inferior point of the chin.

To perform facial measurements, a vertical reference line was created at 70° to the line connecting tragus and nasion (Fig 1). Selection of this line was based on previous results regarding soft tissue analysis from profile images.[27] To assess its reliability and reproducibility, a pilot study of 30 randomly selected subjects from this sample was performed; it showed that, when the head is adjusted in natural head position, the line between tragus and nasion forms a 70° angle with a true vertical line ($\mu = 69.83$; SD, 1.95). The vertical reference line was called the tragus line. The facial profile was described with the linear and angular measurements included in Table I. All measurements were performed automatically in Viewbox after landmark identification by 1 operator (L.K.) and were exported directly to an Excel worksheet (Microsoft, Redmond, Wash).

Table II. Sex dimorphism of facial profile measurements

	Sex	*n*	*Mean*	*SD*	P *value*
A-point–B-point to tragus line	M	711	3.10	1.63	<0.001
	F	919	2.50	1.43	
Upper lip to tragus line	M	711	3.36	1.95	<0.001
	F	919	3.00	1.78	
Lower lip to tragus line	M	711	2.74	2.21	<0.001
	F	919	2.19	2.05	
Pogonion to tragus line	M	711	1.5	3.01	<0.001
	F	919	0.94	2.83	
Convexity subnasale	M	711	170.3	6.3	0.206
	F	919	170.7	6.28	
Tragus pogonion to tragus-subnasale (%)	M	711	114.40	4.77	0.007
	F	919	113.78	4.56	
Tragus-nasion to tragus-subnasale (%)	M	711	97.40	3.28	<0.001
	F	919	98.45	3.26	
Tragus–A-point to tragus-subnasale (%)	M	711	100.76	1.25	<0.001
	F	919	100.38	1.11	
Tragus–B-point to tragus-subnasale (%)	M	711	105.01	3.73	0.469
	F	919	105.15	3.40	
Lower facial height (%)	M	711	59.70	2.31	<0.001
	F	919	58.97	2.24	
Upper facial height (%)	M	711	42.16	2.35	<0.001
	F	919	42.83	2.30	

M, Male; *F*, female.

To test the error of the method, 200 randomly selected photographs were redigitized 4 weeks after the initial digitization by the same examiner, and the measurements were exported to an Excel worksheet. The Bland-Altman plots[28] for the 2 measurements showed high agreement, and thus the random error of the method was judged to be nonsignificant (Appendix Fig 1). The Dahlberg's error[29] ranged from 0.41 to 0.67 mm for linear measurements and from 0.45° to 0.77° for angular measurements. Information regarding the error of the method for the clinical examination can be found in a previous publication.[26]

Statistical analysis

Profile differences between men and women were explored by independent-sample *t* tests for all facial profile measurements (Table II). Significant sex dimorphism

Table III. Multiple regression models for overjet and overbite

	Sex	R^2	P *value*
Overjet	Male	0.296	<0.001
	Female	0.279	<0.001
Overbite	Male	0.200	<0.001
	Female	0.167	<0.001

Predictors (constant): A-point–B-point to tragus line, tragus–A-point to tragus-subnasale, tragus-nasion to tragus-subnasale, lower facial height, tragus-pogonion to tragus-subnasale, upper lip to tragus line, tragus–B-point to tragus-subnasale, convexity subnasale, lower lip to tragus line, pogonion to tragus line, A-point to tragus line, upper facial height, B-point to tragus line.

was found for most variables under examination; thus, we decided to stratify our data based on sex for all further analyses.

To test the association between angular and linear profile measurements, overjet and overbite, multiple linear regression models were developed. Overjet and overbite were considered as our dependent variables, and all profile measurements were treated as independent variables.

Normality and linearity assumptions were tested with histograms and probability plots of the regression standardized residual values for overjet and overbite (Appendix Fig 2, a-b; Supplemental material). Based on the graphic displays and the large sample size, multiple linear regression models were considered to be optimal tests to analyze our data.

RESULTS

There were significant moderate correlations between facial profile and overjet in men ($R^2 = 0.296$) and women ($R^2 = 0.279$), but the correlation was more pronounced in men (Table III). Overbite was less affected by profile measurements (R^2 in men = 0.200; R^2 in women = 0.167); however, these associations were statistically significant for both sexes (Table III).

When the standardized coefficient beta for each profile measurement (independent variables) was examined, it appeared that some have a more significant effect on overjet and overbite than do others (Table IV). The anteroposterior position of the upper lip (upper lip to tragus line) was strongly associated with overjet compared with other factors. Furthermore, the positions of soft tissue A-point and B-point to the face (tragus–A-point/tragus-subnasale and tragus–B-point/tragus subnasale) were also highly weighted factors in the multiple regression models for both sexes. The position of the soft tissue chin as related to the vertical reference line (pogonion to tragus line) and as related to the face (tragus-pogonion/tragus-subnasale) did not appear to have a significant association. The individual effects of all measurements are given in Table IV.

Table IV. Standardized coefficients beta for male and female subjects in the entire sample

	Dependent variable/sex	*Standardized coefficients beta*	P *value*
A-point–B-point to tragus line	Overjet/male	1.050	0.339
	Overjet/female	1.390	0.080
	Overbite/male	0.935	0.424
	Overbite/female	−1.496	0.079
Upper lip to tragus line	Overjet/male	0.730	<0.001
	Overjet/female	0.897	<0.001
	Overbite/male	0.286	0.035
	Overbite/female	0.362	0.026
Lower lip to tragus line	Overjet/male	−0.429	0.002
	Overjet/female	0.053	0.708
	Overbite/male	−0.239	0.098
	Overbite/female	−0.439	0.004
Pogonion to tragus line	Overjet/male	0.176	0.436
	Overjet/female	0.208	0.378
	Overbite/male	0.331	0.169
	Overbite/female	0.176	0.436
Convexity subnasale	Overjet/male	−0.084	0.423
	Overjet/female	−0.224	0.035
	Overbite/male	0.109	0.328
	Overbite/female	−0.118	0.301
Tragus pogonion to tragus-subnasale (%)	Overjet/male	−0.012	0.916
	Overjet/female	0.020	0.844
	Overbite/male	0.081	0.505
	Overbite/female	0.209	0.059
Tragus-nasion to tragus-subnasale (%)	Overjet/male	−0.469	<0.001
	Overjet/female	−0.413	<0.001
	Overbite/male	−0.448	<0.001
	Overbite/female	−0.084	0.423
Tragus–A-point to tragus-subnasale (%)	Overjet/male	0.349	<0.001
	Overjet/female	0.417	<0.001
	Overbite/male	0.240	<0.001
	Overbite/female	0.349	<0.001
Tragus–B-point to tragus-subnasale (%)	Overjet/male	−0.567	<0.001
	Overjet/female	−0.556	<0.001
	Overbite/male	−0.569	<0.001
	Overbite/female	−0.567	<0.001
Lower facial height (%)	Overjet/male	−0.493	0.029
	Overjet/female	−0.185	0.327
	Overbite/male	−0.108	0.653
	Overbite/female	−0.493	0.029
Upper facial height (%)	Overjet/male	−0.644	0.008
	Overjet/female	−0.250	0.219
	Overbite/male	−0.098	0.706
	Overbite/female	−0.644	0.008

Most observed overjet and overbite values were within normal limits. Of 1630 subjects, 1313 (80.55%)

Table V. Standardized coefficients beta in subjects with extreme overjet and overbite values

	Dependent variable	*Standardized coefficients beta*	P *value*
A-point–B-point to tragus line	Overjet ≥5	−0.198	0.903
	Overjet ≤0	−0.131	0.980
	Overbite ≥5	−0.625	0.645
	Overbite ≤0	−2.469	0.570
Upper lip to tragus line	Overjet ≥5	0.810	0.001
	Overjet ≤0	2.427	0.003
	Overbite ≥5	−0.333	0.086
	Overbite ≤0	0.008	0.990
Lower lip to tragus line	Overjet ≥5	−0.505	0.047
	Overjet ≤0	−2.349	0.002
	Overbite ≥5	0.093	0.656
	Overbite ≤0	0.203	0.736
Pogonion to tragus line	Overjet ≥5	−0.357	0.357
	Overjet ≤0	−0.717	0.565
	Overbite ≥5	0.240	0.482
	Overbite ≤0	1.756	0.101
Convexity subnasale	Overjet ≥5	0.023	0.910
	Overjet ≤0	−0.760	0.056
	Overbite ≥5	0.035	0.841
	Overbite ≤0	0.278	0.477
Tragus pogonion to tragus-subnasale (%)	Overjet ≥5	0.121	0.545
	Overjet ≤0	0.673	0.069
	Overbite ≥5	0.286	0.109
	Overbite ≤0	−0.102	0.775
Tragus-nasion to tragus-subnasale (%)	Overjet ≥5	−0.133	0.625
	Overjet ≤0	0.590	0.251
	Overbite ≥5	0.019	0.930
	Overbite ≤0	−0.360	0.451
Tragus–A-point to tragus-subnasale (%)	Overjet ≥5	0.301	0.010
	Overjet ≤0	−0.166	0.601
	Overbite ≥5	0.122	0.235
	Overbite ≤0	−0.110	0.647
Tragus–B-point to tragus-subnasale (%)	Overjet ≥5	−0.491	0.008
	Overjet ≤0	−0.095	0.814
	Overbite ≥5	−0.482	0.004
	Overbite ≤0	0.102	0.783
Lower facial height (%)	Overjet ≥5	0.018	0.961
	Overjet ≤0	−1.156	0.323
	Overbite ≥5	0.114	0.728
	Overbite ≤0	0.476	0.649
Upper facial height (%)	Overjet ≥5	0.009	0.982
	Overjet ≤0	−1.017	0.416
	Overbite ≥5	0.210	0.543
	Overbite ≤0	0.547	0.623

had an overjet between 1 and 4 mm, and 1158 (71.04%) had an overbite between 1 and 4 mm. To obtain more specific information regarding subjects with severe anterior malocclusions, a separate analysis was performed on subgroups with extreme overbite and overjet values (Table V). Our multiple linear regression analyses showed that the facial soft tissue measurements could not accurately predict the severity of the malocclusion in most subgroups. There were moderate correlations between facial characteristics and severe positive overjet ($R = 0.4$; $P < 0.001$), deepbite ($R = 0.342$; $P < 0.001$), and open bite ($R = 0.387$; $P = 0.509$). However, in the negative overjet subgroup, the facial soft tissue measurements predicted 44.2% of the variation in overjet value, indicating a strong association between facial morphology and negative overjet ($R = 0.665$; $P = 0.011$) (Table VI).

Table VI. Multiple regression models for extreme overjet and overbite values

	Value	*n*	*Mean*	R^2	P *value*
Overjet	≥5	261	6.30	0.163	<0.001
	≤0	56	−0.70	0.442	0.011
Overbite	≥5	389	5.81	0.117	<0.001
	≤0	84	−0.48	0.150	0.509

Predictors (constant): A-point–B-point to tragus line, tragus–A-point to tragus-subnasale, tragus-nasion to tragus-subnasale, lower facial height, tragus-pogonion to tragus-subnasale, upper lip to tragus line, tragus–B-point to tragus-subnasale, convexity subnasale, lower lip to tragus line, pogonion to tragus line, A-point to tragus line, upper facial height, B-point to tragus line.

DISCUSSION

We explored the associations between anteroposterior occlusal relationships (overjet), vertical occlusal relationships (overbite), and soft tissue profile characteristics in a large homogenous population of white adults of Finnish ancestry. Our results showed that soft tissue profile measurements could predict only a weak to moderate percentage of the variability in overjet and overbite in the total sample. However, in subjects with negative overjet and mandibular prognathism, soft tissue profile was highly correlated with overjet. Clinically, this denotes that although there are notable visual differences between profiles, a lateral photograph is unlikely to provide adequate information regarding a patient's anterior occlusal relationships, except for those with negative overjet, where an accurate impression about the occlusion can be formed from a photograph.

In orthodontics, the role of the anterior dentition in determining soft tissue profile is heavily considered during diagnosis and treatment planning.[30] Many times, decisions regarding tooth extractions are based primarily on the desired effect on the profile[31]; however, this effect might not always be achieved because of the many factors affecting soft tissue treatment outcomes.[32,33] Although we did not test any treatment effects on the soft tissue profile, this study provides helpful clinical information regarding the role of anterior occlusion in mature adults seeking orthodontic care.

As part of the growth process, facial tissues undergo significant changes over the course of a lifetime,[24] with more pronounced changes in men.[21] In mature adults, facial changes mostly include lip lengthening and flattening, in addition to increases in nose and chin projection.[20,22] Our subjects were 46 years old, which means that natural soft tissue changes had already occurred to a large extent. Lengthening of the upper lip changes its resting point on the maxillary incisors to a higher position; thus, the response of the lip to the underlying occlusion could be poorer compared with younger persons with high tonicity of the facial structures. If this assumption were accepted, age-related changes would weaken the impact of occlusion on the profile; this was evident by our results. However, there were significant sex differences, similar to those reported by previous investigations on adult populations, with women showing less lip and chin projection than men (Table II).[23]

The weak to moderate association between soft tissue profile, overbite, and overjet also needs to be viewed in the context of the parameters of the examined population's occlusal parameters. Most participants had normal overjet and overbite, and extreme malocclusions were less represented in our sample. Due to the large phenotypic variability in patients with various dental relationships, it is likely that a mild to moderate malocclusion does not create distinct profile changes.[34,35] A severe malocclusion changes facial appearance more noticeably and can have a negative impact on how a face is viewed by the public.[36] Therefore, we assessed subjects with extreme overjet and overbite values separately to explore potential correlations unique to these subgroups. It appeared that, even in subjects with severe anterior interarch malocclusions, these did not have a profound effect on the soft tissue profile, with the exception of extreme negative overjet (Table V). Previous investigators have also found a significant association between Class III malocclusion and soft tissue profile measurements, indicating a particularly high diagnostic value for profile pictures in these patients.[18]

Despite the overall weak effect of anterior occlusion on soft tissue profile, certain facial features appeared to be more associated with overbite and overjet than others (Table IV). Soft tissue A-point, soft tissue B-point, and the upper and lower lips appeared to statistically influence the results of the regression model more than other measurements. It may be presumed that they relate better to underlying skeletal differences between subjects. To create predictive models and improve the diagnostic value of facial photographs, measurements including these structures could be beneficial.

From a clinical viewpoint, this study provides important information regarding the relationship of overbite, overjet, and profile appearance in middle-aged adults. The key motivational factors for those seeking orthodontic treatment range from an esthetically pleasing dentition and smile[37] to improving the overall esthetic appearance of the face in patients who also require orthognathic surgery.[38,39] In this context, our investigation helps clinicians to better understand the potential facial impact of malocclusion on patients as they mature.

We used 2-dimensional photographs to evaluate soft tissue profile structures. A 3-dimensional facial assessment would have provided more comprehensive information regarding soft tissue morphology. Furthermore, these results would have been well supplemented and more complete if information regarding lip thickness had been available.

CONCLUSIONS

In mature adults with normal occlusion or increased positive overjet, anterior vertical and sagittal interarch relationships (overjet and overbite) have a weak to moderate impact on the soft tissue profile as viewed on a 2-dimensional image. Therefore, it is not reliable to form an opinion about a patient's occlusion by visually inspecting a 2-dimensional profile photograph, despite obvious differences in profiles between persons.

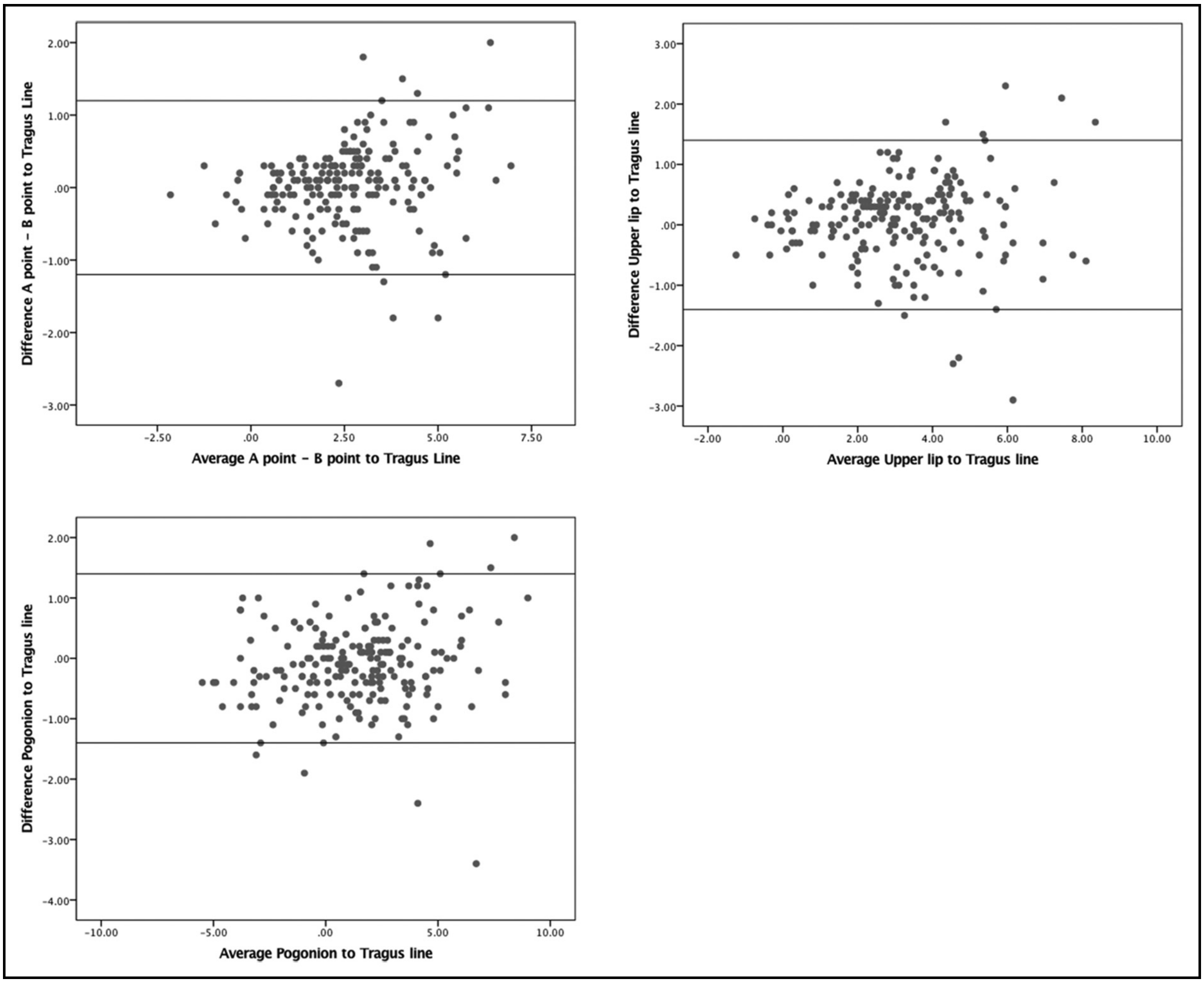
In extreme cases of anterior negative overjet, however, a profile photograph provides significantly relevant information regarding the underlying occlusal relationships of the anterior teeth. It appears that the severity of mandibular prognathism increases with the severity of negative overjet.

ACKNOWLEDGMENTS

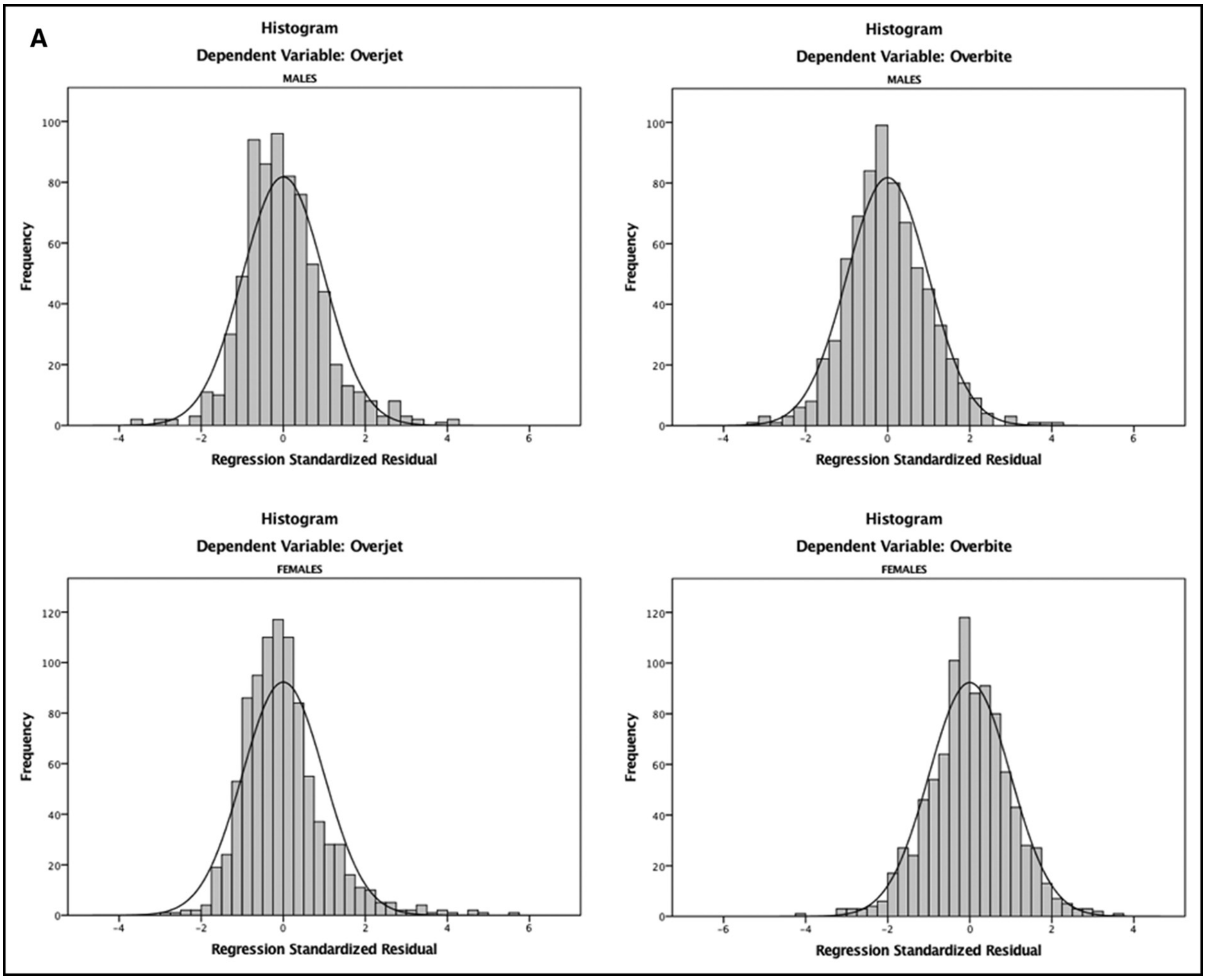
We thank the late Paula Rantakallio (launch of Northern Finnish Birth Cohort 1966), the participants in the 46-year study, the cohort's project center, and Demetrios Halazonetis for his guidance in using Viewbox software and valuable advice during this investigation.

REFERENCES

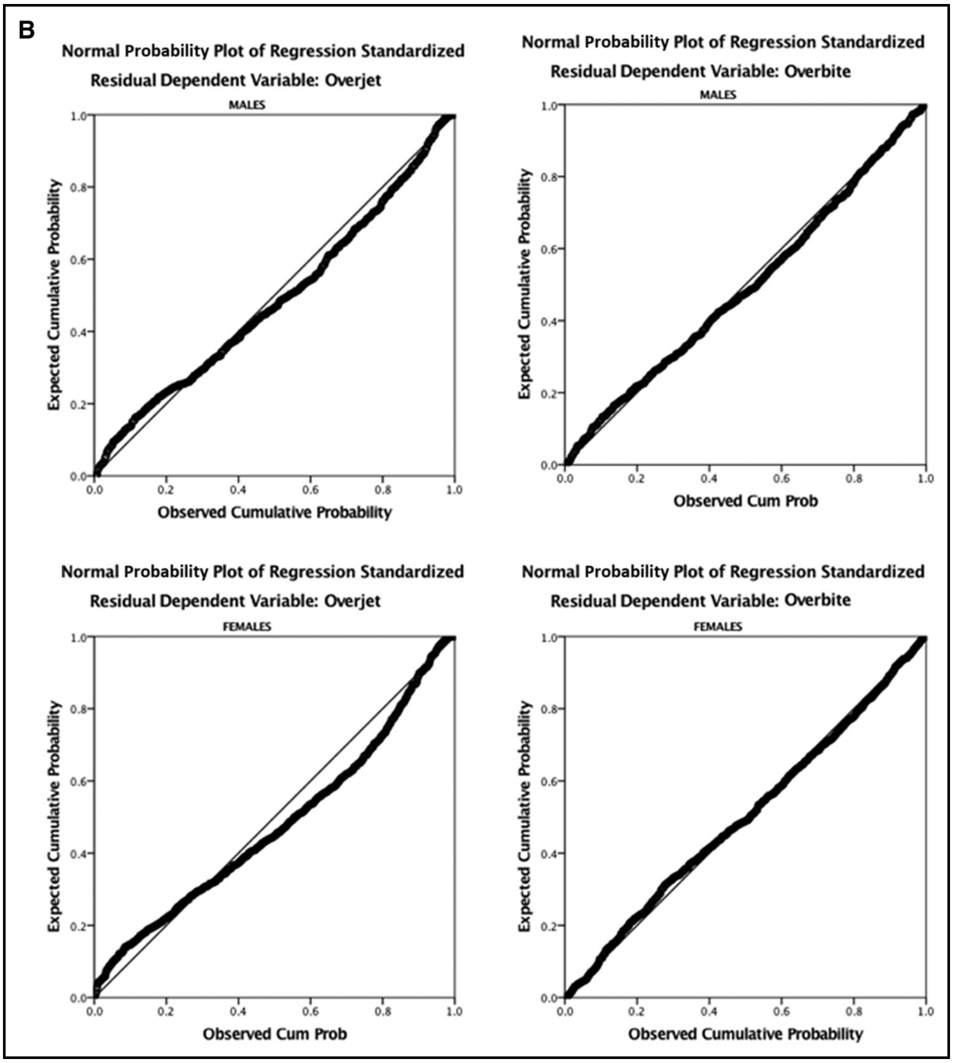
1. Spyropoulos M, Halazonetis D. Significance of the soft tissue profile on facial esthetics. Am J Orthod Dentofacial Orthop 2001;119:464-71.
2. Silvola A, Varimo M, Tolvanen M, Rusanen J, Lahti S, Pirttiniemi P. Dental esthetics and quality of life in adults with severe malocclusion before and after treatment. Angle Orthod 2014;84:594-9.
3. McKiernan E, McKiernan F, Jones M. Psychological profiles and motives of adults seeking orthodontic treatment. Int J Adult Orthodon Orthognath Surg 1992;7:187-98.
4. Nurminen L, Pietilä T, Vinkka-Puhakka H. Motivation for and satisfaction with orthodontic-surgical treatment: a retrospective study of 28 patients. Eur J Orthod 1999;21:79-87.
5. Turley PK. Evolution of esthetic considerations in orthodontics. Am J Orthod Dentofacial Orthop 2015;148:374-9.
6. Halazonetis D. From 2-dimensional cephalograms to 3-dimensional computed tomography scans. Am J Orthod Dentofacial Orthop 2005;127:627-37.
7. Manosudprasit A, Haghi A, Allareddy V, Masoud MI. Diagnosis and treatment planning of orthodontic patients with 3-dimensional dentofacial records. Am J Orthod Dentofacial Orthop 2017;151:1083-91.
8. Burhardt L, Livas C, Kerdijk W, van der Meer WJ, Ren Y. Treatment comfort, time perception, and preference for conventional and digital impression techniques: a comparative study in young patients. Am J Orthod Dentofacial Orthop 2016;150:261-7.
9. Chang YJ, Ruellas AC, Yatabe MS, Westgate PM, Cevidanes LH, Huja SS. Soft tissue changes measured with three-dimensional software provides new insights for surgical predictions. J Oral Maxillofac Surg 2017;75:2191-201.
10. Dimaggio F, Ciusa V, Sforza C, Ferrario V. Photographic soft-tissue profile analysis in children at 6 years of age. Am J Orthod Dentofacial Orthop 2007;132:475-80.
11. Godt A, Bechtold T, Schaupp E, Zeyher C, Koos B, Baas E, et al. Correlation between occlusal abnormalities and parameters investigated by three-dimensional facial photography. Angle Orthod 2013;83:782-9.
12. Arnett G, Bergman R. Facial keys to orthodontic diagnosis and treatment planning—part II. Am J Orthod Dentofacial Orthop 1993;103:395-411.
13. Bergman RT. Cephalometric soft tissue facial analysis. Am J Orthod Dentofacial Orthop 1999;116:373-89.
14. Kasai K. Soft tissue adaptability to hard tissues in facial profiles. Am J Orthod Dentofacial Orthop 1998;113:674-84.
15. Saxby P, Freer T. Dentoskeletal determinants of soft tissue morphology. Angle Orthod 1985;55:147-54.
16. Baumrind S, Frantz R. The reliability of head film measurements. 1. Landmark identification. Am J Orthod 1971;60:111-27.
17. Kale-Varlk S. Angular photogrammetric analysis of the soft tissue facial profile of Anatolian Turkish adults. J Craniofac Surg 2008;19:1481-6.
18. Staudt C, Kiliaridis S. Nonradiographic approach to detect Class III skeletal discrepancies. Am J Orthod Dentofacial Orthop 2009;136:52-8.
19. Subtelny J. A longitudinal study of soft tissue facial structures and their profile characteristics, defined in relation to underlying skeletal structures. Am J Orthod 1959;45:481-507.
20. Nanda R, Ghosh J. Facial soft tissue harmony and growth in orthodontic treatment. Semin Orthod 1995;1:67-81.
21. Hoffelder LB, Lima EM, Martinelli FL, Bolognese AM. Soft-tissue changes during facial growth in skeletal Class II individuals. Am J Orthod Dentofacial Orthop 2007;131:490-5.
22. Formby W, Nanda R, Currier G. Longitudinal changes in the adult facial profile. Am J Orthod Dentofacial Orthop 1994;105:464-76.
23. Behrents R. Growth in the aging craniofacial skelton. Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan; 1985.
24. Pecora NG, Baccetti T, McNamara JA Jr. The aging craniofacial complex: a longitudinal cephalometric study from late adolescence to late adulthood. Am J Orthod Dentofacial Orthop 2008;134:496-505.
25. Rantakallio P. The longitudinal study of the northern Finland birth cohort of 1966. Paediatr Perinat Epidemiol 1988;2:59-88.
26. Krooks L, Pirttiniemi P, Kanavakis G, Lähdesmäki R. Prevalence of malocclusion traits and orthodontic treatment in a Finnish adult population. Acta Odontol Scand 2016;74:362-7.
27. Wasserstein A, Shpack N, Yoseph Y, Geron S, Davidovitch M, Vardimon A. Comparison of lateral photographic and radiographic sagittal analysis in relation to Angle's classification. J Orofac Orthop 2015;76:294-304.
28. Bland JM, Altman DG. Comparing methods of measurement: why plotting difference against standard method is misleading. Lancet 1995;346:1085-7.
29. Dahlberg G. Statistical methods for medical and biological students. New York: Interscience Publications; 1940.
30. Cheng HC, Cheng PC. Factors affecting smile esthetics in adults with different types of anterior overjet malocclusion. Korean J Orthod 2017;47:31-8.
31. Iared W, Koga da Silva EM, Iared W, Rufino Macedo C. Esthetic perception of changes in facial profile resulting from orthodontic treatment with extraction of premolars: a systematic review. J Am Dent Assoc 2017;148:9-16.
32. Kiekens RM, Kuijpers-Jagtman AM, van 't Hof MA, van 't Hof BE, Straatman H, Maltha JC. Facial esthetics in adolescents and its relationship to "ideal" ratios and angles. Am J Orthod Dentofacial Orthop 2008;133:188.e1-8.
33. Rains M, Nanda R. Soft-tissue changes associated with maxillary incisor retraction. Am J Orthod 1982;81:481-8.
34. Moreno-Uribe L, Howe S, Kummet C, Vela K, Dawson D, Southard T. Phenotypic diversity in white adults with moderate to severe Class II malocclusion. Am J Orthod Dentofacial Orthop 2014;145:305-16.
35. Moreno-Uribe L, Vela K, Kummet C, Dawson D, Southard T. Phenotypic diversity in white adults with moderate to severe Class III malocclusion. Am J Orthod Dentofacial Orthop 2013;144:32-42.
36. Richards M, Fields HJ, Beck F, Firestone AR, Walther DB, Rosenstiel S, et al. Contribution of malocclusion and female facial attractiveness to smile esthetics evaluated by eye tracking. Am J Orthod Dentofacial Orthop 2015;147:472-82.
37. Pabari S, Moles D, Cunningham S. Assessment of motivation and psychological characteristics of adult orthodontic patients. Am J Orthod Dentofacial Orthop 2011;140:263-72.
38. Johnston C, Hunt O, Burden D, Stevenson M, Hepper P. Self-perception of dentofacial attractiveness among patients requiring orthognathic surgery. Angle Orthod 2010;80:361-6.
39. Meade EA, Inglehart MR. Young patients' treatment motivation and satisfaction with orthognathic surgery outcomes: the role of possible selves. Am J Orthod Dentofacial Orthop 2010;137:26-34.



Appendix Fig 1. Random error of the method tested with Bland-Altman plots.



Appendix Fig 2. Histograms and probablility plots showing the normality and linearity of the data.



Appendix Fig 2. (*continued*).