Relationship between anteroposterior maxillomandibular morphology and masticatory jaw movement patterns

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The causal relationships between oral function and craniomandibular morphology are poorly understood. The aim of this study was to determine whether quantifiable features of masticatory jaw movements and associated EMG activity correlated with variation in morphology as defined by the ANB angle. Thirty-six healthy subjects with no previous orthodontic treatment, asymptomatic masticatory muscles, and asymptomatic temporomandibular joints participated. While subjects chewed gum, jaw movement data and surface EMG data were digitized and then quantified into a 300 variable vector for each subject. ANB angle measurements were calculated from digitized tracings of lateral cephalographs. Step-wise linear regression and discriminant analyses were used to determine the relationship between the ANB angle and a subset of the variables defining jaw movement patterns and EMG patterns. A linear combination of seven jaw movements and EMG variables accounted for over 75% of the variation in the ANB angle (adjusted R^2 = 0.78, $P < .001$). A jackknifed cross-validation of the discriminant analysis, which was forced to use the same seven variables as the regression analysis, resulted in correct classification of 14 of 20 skeletal Class I, 7 of 9 skeletal Class II, and 7 of 7 skeletal Class III subjects. These results suggest that there is an association between anteroposterior skeletal morphology, as quantified by the ANB angle, and masticatory jaw movement patterns, as quantified in this study. (Am J Orthod Dentofacial Orthop 1999;115:258-66)

The relationship between dentoskeletal form and oral function is complex and poorly understood. To gain insight into this relationship, investigations have used bite force,[1-6] electromyographic (EMG) activity,[3,6-12] and jaw movement parameters[10,13-18] to define function operationally, and tooth form,[5,19] cephalometric parameters,[1,2,5,8-10,20-25] and histologic or anatomic parameters[4,26-30] to define morphology operationally. Most such investigations have reported correlations between such form and function parameters (however, cf references 15, 16, and 31).

Although correlations between function and morphology have been found, the causal relationships remain unclear. Some investigators have hypothesized that occlusion and facial form contribute to functional variation.[17,18,32,33] Others suggest that functional parameters and EMG muscle activity patterns are significant factors contributing to occlusal schemes,[9,34] mandibular form,[1,22,23,28] condylar growth and morphology,[4,27] and to the growth and development of other maxillofacial anatomic structures.[1,5,24,25,29,30] It is also possible that dentoskeletal morphology and neuromuscular anatomy, physiology, and function could codevelop, thereby optimizing each other according to as yet undetermined self-organizing principles. Recent mathematical advances[35,36] may make scientific investigations of such nonlinear interactions approachable in the future.

Whatever the case, before specific hypotheses regarding the causal relationships between form and function can be tested, it is necessary to have a baseline quantitative classification of masticatory "styles" in the permanent dentition state. If distinct masticatory styles were exclusively associated with specific dentofacial patterns, then it may be possible to track the development of these masticatory styles, to determine when they become manifest, and to test whether they provide predictive power with regard to parameters of dentoskeletal growth and development.

Toward these ends, we undertook the current study to test the hypothesis of whether quantifiable masticatory features correlated with classification of skeletal anteroposterior relationships defined by the ANB angle. The study used a previously developed multivariate quantitative description of mastication.[37] This description is conceptually similar to cephalometrics in

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that discrete landmarks in jaw movement and EMG records were first located and marked. Spatiotemporal measurements between these landmarks were then used to generate variables describing mastication. Masticatory parameters were used to define oral function, because of all oral functions, mastication is arguably the most demanding on the developing skull and mandible.[38] Hence, mastication may play an important role in dentoskeletal growth and development.

SUBJECTS AND MATERIALS

Thirty-six healthy 18 to 27 year old adults, 21 men and 15 women, were studied. Candidates were solicited from undergraduate dental classes at the University of Michigan School of Dentistry. Candidates presenting to the laboratory underwent an extensive health history and clinical examination screening. Details of the screening procedure have been reported elsewhere.[37] Briefly, screening tools consisted of methods used at the UCLA TMJ and Facial Pain Clinic, the University of Michigan Facial Pain Clinic, and published diagnostic criteria.[39] Laboratory screening results were used to develop the final subject pool. Candidates were excluded if they met the following criteria: (1) their general health did not allow them to participate in the study; (2) they reported a history of orofacial pain (VAS scores > 25/100 mm); (3) they were missing teeth other than third molars; (4) they reported a history of arthritis, temporomandibular joint (TMJ) noises, or restricted jaw movements (eg, maximum opening < 40 mm); (5) they had outstanding dental health problems; (6) they reported a history of organic disease; (7) they had used drugs that could interfere with affective or motor parameters; (8) they were > 15% overweight, thus making it difficult to obtain clear EMG signals; (9) they had a history of orthodontic treatment. Of the ~ 80 candidates presenting for screening, 36 met these criteria and were used in the study. Informed consents were obtained from subjects, and their rights and identities were protected. Only the general nature of the study was explained to the subjects, ie, “we are studying gum chewing,” and to the clinicians and experimenters involved directly with the subjects.

Experimental Setup

Each subject was seated upright in a laboratory chair, and electrode pairs (Grass E6SH, Grass Instruments, Quincy, Mass.) were secured over the right and left anterior temporalis and superficial masseter muscles. A reference electrode (Grass E34D-S, Grass Instruments) was placed on the subject’s left ear.

A mandibular kinesiograph (K5AR, Myotronics, Seattle, Wash.) tracked jaw movements. Protocols used to standardize kinesiograph placement were as follows. A modified Fox bite plane was outfitted with a bubble level. The bite plane was placed intra-orally so that it touched the subject’s maxillary premolars and molars bilaterally by having the subject bite gently against cotton rolls placed on the occlusal surfaces of the mandibular dentition. The subject’s head was carefully manipulated until the bubble level registered horizontal in both the lateral and anteroposterior dimensions. Next, the kinesiograph eyeglass frames were fitted and customized to the subject’s nose with heavy-bodied polyvinylsiloxane impression material (Kerr, Romulus, Mich.). A second bubble level, placed on the eyeglass frames with wax, was leveled to the bubble on the Fox bite plane. Subsequently, the bite plane was removed, and the bubble level on the eyeglass frame was used to keep the subject’s occlusal plane parallel to the horizontal.

The kinesiograph sensor array was then fitted with an acrylic jig made to hold the magnet in a fixed position against the subject’s teeth relative to the array. The jig was created before the study began by attaching the eyeglass frame and magnet to a stereotaxic micromanipulator, and zeroing the magnet with respect to the sensor array according to the kinesiograph instruction manual. The same jig was used on all subjects to attach the magnet to the lower incisors in a standardized position relative to the sensor array.

The sensor array was also fitted with a permanently attached bubble level. While the subject clenched in centric occlusion, one investigator standardized the subject’s head position by referencing the bubble level on the eyeglass frame, and another investigator placed the sensor array on the eyeglass frame and manipulated the array until (1) the magnet in the jig was positioned on the subject’s lower central incisors and out of contact with maxillary teeth, (2) the bubble level on the array was level with the horizontal plane, and (3) the array frame’s lateral or *x*-axis was parallel to the subject’s frontal plane. Then the sensor array was tightened to the eyeglass frame and the magnet was attached to the teeth with urihesive (Squibb, Princeton, NJ). After the array and magnet were secured, the jig was carefully removed. Thus the array frame was perpendicular to subjects’ occlusal planes, and parallel to their frontal planes, and the magnet was attached to the lower central incisors in a between-subject, standardized position relative to the sensor array.

The kinesiograph generated three voltage signals proportional to jaw movements in the lateral, vertical, and anteroposterior dimensions. Each signal was run in a separate channel to an A/D board and digitized at 1200Hz (Peak Performance A/D Interface Unit and

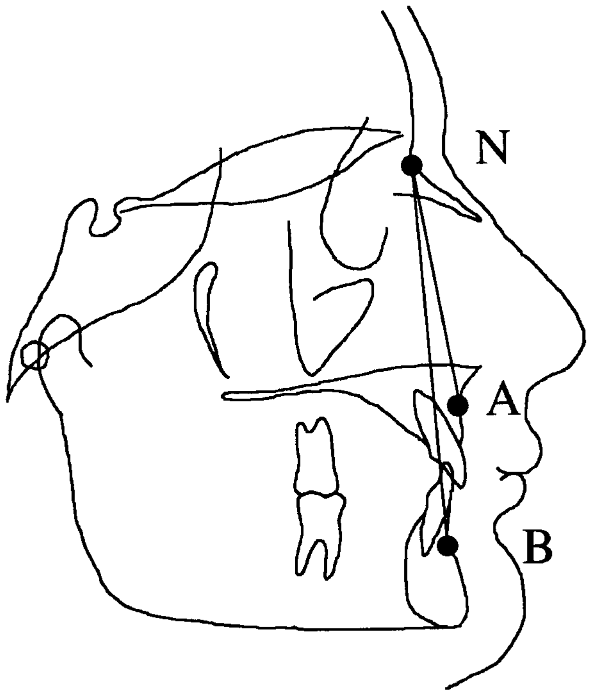

Fig 1. Cephalograph tracing of one subject. ANB angle is indicated.

software, Peak Performance, Inc, Englewood, Colo; IBM compatible 386/87 computer).

Data Acquisition

Once the experimental setup was complete, subjects were given a gum-base pellet (~ 8 to 10 mm diameter, Wrigley's, Chicago, Ill) and told to chew for several minutes before the experiment began. At this point, investigators left the room or engaged in activities while ignoring the subject. During this time and ~ 1 to 2 minutes after subjects had been given the gum, digitization of the subject's jaw movements was begun by remote trigger. These procedures were followed, because we have found that chewing parameters similar to those obtainable under routine, everyday conditions can be obtained when investigators leave the room and ignore the subject.[40,41] Data digitization continued for 15 seconds.

Jaw Movement and EMG Data Processing

EMG data were electronically amplified (total gain = 10,000, physiological pre-amps and amplifiers, Med Associates, St. Albans, Vt), digitized at 1200 Hz (Peak Performance A/D interface unit and software, Peak Performance, Inc., Englewood, CO), and off-line notch-filtered (60 Hz) and band-pass-filtered (20-600 Hz, Datapac II software, RUN Technologies, Laguna Hills, Calif). Waveforms representing jaw movements were digitized at 1200 Hz at the same time and in the same way as the EMG data. Subsequently, jaw movement data were compressed (compression ratio = 20), smoothed (window = 3.332 ms), and then first and second order derivatives of the original jaw movement waveforms were created (Datapac II, RUN Technologies).

Data Quantification and Analysis

All University of Michigan dental students are required to have lateral cephalographs taken during their first year of dental school. Subjects in the study made these cephalographs available, and cephalogram tracings were carefully made by a trained research orthodontist. Subsequently, the positions of points A, N, and B were digitized, and the ANB angle measurement was calculated by software (Dentofacial Planner, London, Ont.). Fig 1 shows a cephalogram of one subject including the ANB angle.

Data were quantified chewing cycle-by-chewing cycle. For purposes of this study, a chewing cycle began at the previous cycle's point of maximum jaw closure and ended at the subsequent point of maximum jaw closure. Maximum jaw closures were detected by identifying local maxima in the subjects' vertical jaw movement component waveforms. An algorithm created in the laboratory searched the waveform for these local maxima. Waveform segments between two successive local maxima defined each cycle.

Data were quantified as follows. A computer program created in the laboratory determined the spatiotemporal position of the landmarks shown in Fig 2. Variables describing the location in time or space of these landmarks with respect to each other were calculated. This resulted in a $150 \times n$ matrix, where n = number of chewing cycles sampled during the 15 second trial. This matrix was reduced and transformed into a 1×300 vector by calculating the means and variances of all 150 variables for the n chewing cycles sampled for a given subject (150 means + 150 variances = 300 variables per subject). The variables have been described in detail elsewhere[37] with the following exceptions. In previous work, data were collected with a device that allowed angular measures (eg, gape angle in the sagittal plane, etc.) to be calculated.[37] Angular measurements were not possible to make with the kinesiograph; hence, they were replaced with linear displacement measurements (eg, gape in the vertical plane measured from *y max 1* to *y min*, see Fig 2). This resulted in the 150 mean variable measures in the current study as opposed to the 165 mean variable measures reported in the previous study.[37] The

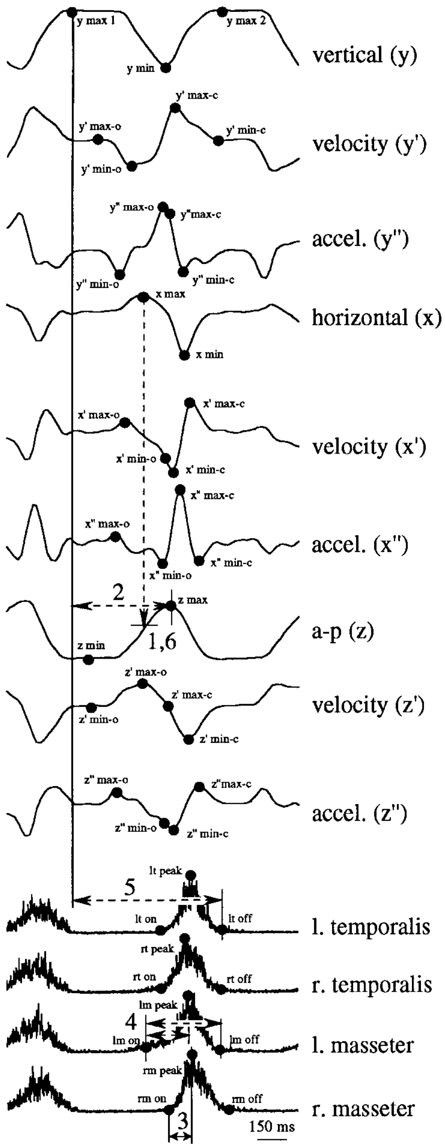

Fig 2. Averaged jaw movement and EMG data of one subject. Data are shown in time series format. (*Bullets* on traces = landmarks used to create variables. Traces, top to bottom: vertical jaw movement component (y); first derivative of y; second derivative of y; lateral jaw movement component (x); first derivative of x; second derivative of x; anteroposterior jaw movement component (z); first derivative of z; second derivative of z; left and right anterior temporalis muscle EMG; left and right superficial masseter muscle EMG. Abbreviations: min = minimum value in respective cycle phase; max = maximum value in respective cycle phase; -o = jaw opening cycle-phase; -c = jaw closing cycle-phase; on = EMG burst onset; off = EMG burst offset; peak = EMG peak amplitude. Vertical line drawn through *y max 1* (top trace) = chewing cycle onset. Numbers 1-6 indicate variables and correspond to the number labels for variables in Table IV.)

Table I. ANB statistics by subject group

Group	*Mean (SD)*	*Minimum*	*Maximum*
Class III	0.19° (0.68°)	–1.1°	0.9°
Class I	3.03° (0.81°)	1.3°	4.6°
Class II	6.46° (1.44°)	5.0°	9.7°

Table II. ANOVA of stepwise linear regression

Source of variation	*Sum of squares*	*DF*	*Mean square*	*F Ratio*
Regression	166.41	7	23.77	18.80
Residual	35.41	28	1.26	

Table III. Posterior probabilities of group classifications

		Number of cases classified into group		
Group	*% Correct*	*Class III*	*Class I*	*Class II*
Class III	100.0	7	0	0
Class I	70.0	2	14	4
Class II	77.8	0	2	7
Total	77.8			

seven variables included in the analyses are described in this article (see also Fig 2).

Data Analysis

The vectors representing the 36 subjects were used in a stepwise linear regression analysis (BMDP Dynamic 2R, BMDP Statistical Software, Inc, Los Angeles, Calif) using an F-to-enter ≥ 4.0 and an F-to-remove ≤ 3.996. The dependent variable was the ANB angle. A tolerance limit of 0.25 prevented two variables with high collinearity from being entered into the function. The maximum number of steps was set to 7 so that the sample size (N = 36) was > 5 times the number of variables entered into the function.[42]

Because Angle's classification system is a familiar orthodontic classification system, we performed the following adjunct analysis. Cutoffs of the ANB angle were set to generate subject groups as follows: Class II = ANB ≥ 5° (N = 10 subjects; 5 male:5 female); Class I = 1° < ANB < 5° (N = 19 subjects; 13 male:6 female); Class III = ANB ≤ 1° (N = 7 subjects; 3 male:4 female). Table I shows summary statistics of ANB angle measurements for the subject groups.

Next, discriminant functions were generated (BMDP Dynamic 7M Software) by using only those variables that had been included in the aforementioned stepwise linear regression analysis. This discriminant analysis evaluated the jaw movement and

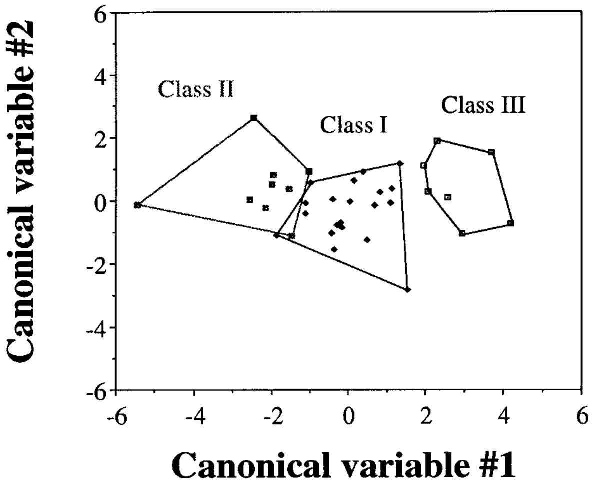

Fig 3. Scatterplot of canonical variable scores of the discriminant analysis.

EMG variables' ability to identify a subject's Angle classification status. A jackknifed cross-validation test was performed to evaluate the calculated posterior probabilities.

Variable Descriptions

The step-wise regression procedure selected 7 of 300 variables for use in the analysis (see Results section). Below are brief descriptions of these seven variables (see also Fig 2).

- z at x max: A measure of jaw retrusion during chewing; 0 mm = centric occlusion. The measurement was made when the jaw had moved to maximum contralateral excursion in the given chewing cycle, ie, *x max* on the *horizontal (x)* plot of Fig 2. Fig 2 shows a dashed vertical line drawn from *x max* to the *a-p (z)* plot. This line ends in an arrow pointing to the horizontal line labeled *1,6*. The point intersection between the *a-p (z)* plot and the horizontal line is *z at x max*. The analysis entered both the mean and variance of *z at x max* into the regression model.
- z max ol/ct: Onset latency (ol) of maximum jaw retrusion, described as a proportion of total cycle time (ct); 0 ms = *y max 1*, Fig 2 top plot. In Fig 2, the dashed horizontal line labeled *2* on the *a-p (z)* plot is *z max ol*. Cycle time is the time between *y max 1* and *y max 2*, Fig 2, top. *zmax ol/ct* is calculated by dividing *z max ol* by cycle time. The variance of *zmax ol/ct* was used in the regression model. This variance provided an index of how variable the timing of maximum retrusion was from cycle to cycle.
- bmass peak ol: EMG peak amplitude onset latency for the balancing-side masseter muscle; 0 ms = EMG burst onset. Fig 2 shows an example for a left-sided chewing cycle; *r. masseter* = balancing masseter EMG. *bmass peak ol* is the time between *rm on* and *rm peak*. The mean of *bmass peak* was included in the regression model. The variable indicates how rapidly maximum EMG amplitude was achieved.
- wmass peak ol/bd: This is similar to *bmass peak ol*, above, with two exceptions: (1) the measurement used the working side masseter EMG, and (2) the measurement was expressed as a proportion of the EMG burst duration. Fig 2 shows an example for a left-sided chewing cycle; *l. masseter* is the working masseter EMG. In this example, peak onset latency is the time between *lm on* and *lm peak*. Burst duration is the time between *lm on* and *lm off*. The mean of *wmass peak ol/bd* was included in the regression model. The variable indicates how rapidly maximum EMG amplitude was achieved with respect to total burst duration.
- wtemp off-y max 1: The time between the start of a chewing cycle and EMG burst offset in the working side temporalis muscle. Fig 2 shows an example for a left-sided chewing cycle; *l. temporalis* is the working temporalis EMG, and the horizontal dashed line labeled *5* indicates how *wtemp off-y max 1* was measured. The mean of *wtemp off-y max 1* was used in the regression model.
- vmax 3d ol/ct: Onset latency of maximum jaw velocity, expressed as a proportion of total cycle time (ct); 0 ms = *y max 1*, Fig 2. This measurement cannot be shown as an example because it occurred in three dimensions. *vmax 3d ol* is the time between *y max 1* and the time at which maximum jaw velocity in three dimensions occurred. The variance of *vmax 3d ol/ct* was used in the regression model. The variable provides an indication of how variable jaw velocity (and by inference muscle activity) was between chewing cycles.

RESULTS

The stepwise linear regression analysis found that a combination of seven jaw movement and EMG variables accounted for > 75% of the variation in the ANB angle (adjusted $R^2 = 0.78$, $P < .001$). Table II shows the analysis of variance results for the linear regression. These results indicate that a statistically significant relationship existed between ANB angle measurements and the combination of seven jaw function variables.

Table III shows jackknifed cross-validation test results of the discriminant analysis in which the seven variables selected by the stepwise regression analysis were used to construct discriminant functions (see Subjects and Materials section). Column 1 designates the known subject group, column 2 shows the percentage of subjects correctly classified by the discriminant functions into the respective groups, and columns 3 through 5 tabulate the number of subjects classified by the model into the groups. The probability of correct classification for the discriminant analysis was 77.8%. In other words, the discriminant analysis could correctly predict the Angle's classification status of 77.8% of the subjects based on information contained in the

Table IV. Variable descriptions, means,* and (1SEM) by subject group

No.†	*Variable*‡	*Class III*	*Class I*	*Class II*
1	z at x max (mean)	0.48 (0.13)	0.39 (0.13)	0.30 (0.12)
2	zmax ol/ct (sd^2)	0.094 (0.075)	0.10 (0.073)	0.14 (0.088)
3	bmass peak ol (mean)	212.1 (58.6)	187.5 (81.3)	142.3 (100.6)
4	wmass peak ol/bd (mean)	0.53 (0.076)	0.61 (0.066)	0.61 (0.068)
5	wtemp off-ymax1 (mean)	907.6 (340.7)	978.9 (286.5)	965.5 (253.7)
6	z at x max (sd^2)	0.062 (0.024)	0.065 (0.027)	0.046 (0.031)
7	vmax 3d ol/ct (sd^2)	0.047 (0.024)	0.049 (0.027)	0.042 (0.029)

*Position measures are in millimeters; time measures are in milliseconds.
†Numbers correspond to the step at which variable was entered into the analysis and also to numbers used in text and in Fig 2.
‡See text for variable descriptions.

seven jaw and EMG variables alone. Note also that no Class III subjects were misclassified and that Class II subjects were only misclassified as Class I.

Fig 3 is a scatterplot derived from the discriminant analysis. This representation makes it easy to see the cluster pattern for each group and how the groups are separated from each other. Note that the greatest separation occurs between the Class III group and the Class II group on the scatterplot's *x*-axis. The relatively high incidence of correct classification for the Class III group subjects (Fig 3 and Table III) suggests that this subject group had chewing features that were unique from the Class I and II subjects. However, the sample size is too small to state this conclusively.

Table IV shows mean (1 SEM) measurements, by subject group, for the seven variables included in the analyses. Note that four variables were means and three were variances. The purpose of using variance was to provide an index of within-trial chewing-cycle variation. Note that for the first three variables listed in Table IV, changes in mean measures either increased or decreased between Class III and Class I and between Class I and Class II subjects. It is primarily these three variables that provide the linear correlation with ANB and the group separation of the first canonical variable (*x*-axis, Fig 3). Variable 1 occurred during jaw opening, variable 2 occurred near maximum opening, and variable 3 occurred during jaw closing. Hence, ANB covaried with aspects of both opening and closing phases of the chewing cycle.

Variables included in step-wise multivariate models are not necessarily statistically significant in univariate tests. As a result, it is not useful or appropriate to discuss the between-group differences in single variable measures. However, the independent variable included at step one (*z at x max*, Table IV) is the variable with the largest F-score when all independent variables are compared singly with the dependent variable. Hence, it is appropriate to discuss this variable briefly. Results show that chewing was characterized by a more retruded jaw position at *x max* for Class III subjects and by a less retruded jaw position at *x max* for Class II. This meant that Class III subjects were actively retruding their jaws further at *x max* than Class I subjects. Likewise, Class I subjects were retruding their jaws further at *x max* than Class II subjects.

DISCUSSION

This study explored whether a relationship existed between the ANB angle and oral function, operationally defined by a linear combination of jaw movement and associated EMG variables representing gum chewing. We first performed a multivariate linear regression to preserve the continuous nature of the ANB angle. However, because Angle's classification is well-known, we performed a discriminant analysis, wherein Angle's skeletal group classifications were identified. Both analyses indicated a highly significant relationship between ANB and seven variables representing jaw movement and associated EMG data. These results suggest the existence of a quantifiable relationship between craniomandibular form and oral function.

In this forward-stepping multivariate analysis, the first step selected the single independent variable with the highest correlation with ANB. This variable was *z at x max* (Table IV). Specifically, Class III subjects retruded their jaws the most, whereas Class II subjects retruded their jaws the least at *x max* (Fig 2). Although the difference between Class II and Class III subjects' retrusion was small (0.2 mm), it was consistent. Furthermore, previous findings indicate that Class II subjects also have a more protruded jaw position during rest as well.[9] Hence, Class III subjects appear to have relatively retruded jaws during both rest and mastication when the teeth are not in contact.

Tooth contact occurs during swallowing and mastication.[43] If Class III subjects make initial contact from a relatively retruded position, as suggested by the results of the current and previous study,[9] then these subjects are likely to experience a substantial anterior slide during tooth contact. During such a slide Class III subjects would experience a larger anteriorly directed force in the mandibular arch than would Class II subjects.

Forces achieved during mastication are at least 20 kg or higher.[44-46] Furthermore, the anteriorly directed component of occlusal forces is surprisingly high at ~25% of the total force value.[47] Although masticatory forces are intermittent, they are applied daily throughout a lifetime. Hence, Class III subjects may have a relatively large anteriorly directed force applied intermittently but daily to the lower jaw. Whether this is the case and whether it plays a role in mandibular development will require further study.

The ANB angle is primarily an index of anteroposterior craniomandibular form. Therefore it would seem reasonable for variables describing the anteroposterior dimension of function to be the best predictors of ANB. Of the four jaw movement variables included in the analysis (viz., variables 1, 2, 6, and 7, Table IV), three represented anteroposterior jaw movement characteristics (1, 2, and 6).

One surprising finding was that three variables included in the analyses (2, 4, and 7) were proportions. Proportions are used to factor out size-dependent features[37]; consequently, we anticipated that the step-wise analyses would exclude such variables. Because proportions were included, perhaps it is more difficult to control for size-dependent features in multivariate analyses than previously expected. Hence, multivariate studies should provide appropriate evidence that size differences are not confounding results.

A unique feature of the study was that subjects were unaware when their jaw movements were recorded. Our previous work indicates that jaw movements can be affected by observation.[40] Obviously, studies interested in developmentally relevant form-function relationships would be compromised by including subjects with a history of orthodontic intervention. We suggest that such studies can also be compromised if functional parameters are affected by contrived experimental conditions. One aim of our work is to minimize functional alterations caused by observation effects. Future studies into the ontogenetic basis of form-function relationships should consider this feature so that results will more likely reflect relationships that exist on daily bases.

The kinesiograph was used to collect jaw movement data because it is easy to use, is well tolerated by subjects, is relatively noninvasive, and is familiar to many dental clinicians. The disadvantage of the device is that nonlinearities inherent in its signals tend to underestimate true jaw displacement values, especially at extrema. Because many of the landmarks used to create variables defined extrema (Fig 2), it is likely that the differences between subject groups were underestimated. A more precise motion analysis system would probably enhance the between-group differences reported in this study.

Recent work indicates that men and women chew differently.[37] Although there were considerably more men than women in the Class I group, the male:female ratio was closely balanced between the Class II and III groups. Because the separation between groups was greatest for these two groups, it is unlikely that our findings were confounded by gender influences. Furthermore, the seven variables used in this study did not differ significantly between men and women (results not shown). Hence, this study's results likely reflect morphology-specific jaw movement differences.

The study used dental students as subjects; hence, general inferences from our results must be guarded. However, because the study's aim was to evaluate the relationship between form and function, the relatively homogenous dental student subject pool controlled for factors irrelevant to the study. Indeed, we found no age, weight, height, or ethnicity differences among our three Angle's groups. Furthermore, we required subjects with good oral hygiene and with no iatrogenically-altered occlusal or dentoskeletal relationships. Because subject self-report was required to obtain this information, we believed dental students would provide more reliable dental histories than subjects without dental training.

This study should be viewed as exploratory; it lays the groundwork for several important future studies. For instance, we will be able to use the methods and results to quantify function in subjects with deciduous dentitions in order to determine whether the functional styles (operationally defined by the linear combination of the seven variables used in this study) guide the developing dentoskeleton. That is, is it possible that children who will ultimately develop Class I or Class III morphologies will chew like their adult counterparts at a stage in their dentoskeletal development when they are still Class II? For instance, do children who will develop Class III dentoskeletal relationships retrude their jaws more during function? If so, can these children be trained to chew like Class I adults? And can such training compliment or even replace some orthodontic therapies?

Another avenue for future research will involve how oral function adapts to surgery. Studies that have looked at chewing in subjects undergoing mandibular advancement have reported few compensatory changes in mandibular function postoperatively, or they have reported changes that take up to 2 years to become realized.[15,48] Future investigations based on the current study's results will ask whether patients undergoing mandibular advancement surgery retain their Class II masticatory "styles" postoperatively. If so, does this mismatch reduce chewing efficiency? Do these patients adapt to Class I chewing styles? Over what time scales does this adaptation occur? What can insights to these questions teach us about neuromuscular plasticity, and the role of function in relapses seen in many cases?

Finally, the current study focused solely on ANB (anteroposterior) aspects of craniomandibular relationships. Future work will evaluate whether there is a relationship between oral function and vertical morphologic features as well.

In summary, it has long been believed that important form-function relationships exist. Form has been quantified using cephalometric techniques. Now, we are applying similar methods to quantify oral function. This will allow us to compare form and function rigorously. The current study suggests that quantitative form-function relationships exist. Future work will evaluate additional morphologic measures and their relationship to function and will use the current study's methods and results in developmental studies to evaluate complex causal form-function relationships.[35,36]

CONCLUSIONS

1. Stepwise linear regression analysis showed a highly significant relationship ($P < .001$) between ANB angle and a combination of seven variables representing jaw and associated masticatory EMG activity during a gum-chewing task.
2. The linear combination of these seven variables accounted for about 78% of the variation in the ANB angle.
3. Jackknifed cross-validation of a stepwise discriminant analysis, in which the seven variables selected by the aforementioned regression analysis were forced into the discriminant functions, found the probability of correct Angle's group classification to be 77.8%.
4. There were no misclassifications between Class II and Class III subjects in the discriminant analysis.
5. Our findings suggest that this multivariate approach to studying oral function will provide a useful tool with which to study form-function relationships.

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