Correlation Between the Length and Sagittal Projection of the Upper and Lower Jaw and the Fundamental Frequency

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Summary: Objective. To report on the correlation between the length and projection of the upper and lower jaw and the fundamental frequency (F_0).

Study Design. Prospective study.

Materials and Methods. A total of 45 healthy subjects were included in this study. The facial skeletal measurements included: SNA, SNB, ANB, angles that reflect the position of the maxilla and mandible in relation to the base of skull and to each others, length of mandible Co-Gn, and length of maxilla PNS-ANS. All subjects underwent acoustic analysis using VISI-PITCH IV.

Results. The means for F_0 and habitual frequency were 220.75 + 40.01 Hz and 216.99 + 43.9 Hz, respectively. The means for SNA, SNB, and ANB were 80.753 ± 3.20, 77.409 ± 3.64, and 3.336 ± 2.57, respectively. The mean length of the mandible and maxilla were 104.28 + 7.94 and 50.29 + 3.94, respectively. In the total group, there was a moderate negative correlation between F_0 and habitual frequency and the length of the mandible ($r = -0.528$ and -0.577, respectively). There was also a moderate negative correlation between F_0 and habitual frequency and the length of the maxilla ($r = -0.473$ and -0.519, respectively). Similar findings were present after excluding the pubertal subjects. With respect to the other cephalometric measurements, the correlation was poor (r value < 0.3).

Conclusions. There is a moderate negative correlation between the length of the upper and lower jaw and the average F_0 and habitual frequency. The remaining facial sagittal projection parameters do not correlate with the average F_0 and habitual frequency.

Key Words: Fundamental frequency–Habitual pitch–Length of the maxilla–Length of the mandible.

INTRODUCTION

Facial skeletal morphology is a division of our body appearance. It is demarcated by the shape and position of the underlying facial skeleton.[1] This later is determined on lateral cephalometric radiograph by various measurements among which are the length of the maxilla, the length of the mandible, and the subspinal-nasion-supramental angle, which reflects the sagittal position of the upper and lower jaws in relation to each others. Variations in these measurements reflect different types of facial morphology described as straight, convex, and concave. Subjects with straight profile for instance have an average length of the mandible and maxilla in relation to age and a subspinal-nasion-supramental angle between 0 and 4°. Whereas subjects with a convex profile have maxillary prognathism and/or mandibular retrognathism reflected by a subspinal-nasion-supramental angle of more than 4° and a recessed chin projection with a micrognathic mandible. On the other hand, a concave profile with a prognathic mandible and/or retrognathic maxilla is reflected by a subspinal-nasion-supramental angle of less than 0° and a strong chin prominence.[2]

Despite the fact that facial morphology is an integral part of the upper airway geometry, which is a major determinant of several acoustic parameters, little has been reported on the correlation between facial skeletal measurements and voice.

There are numerous investigations on the articulatory characteristics of speech in relation to jaw opening indicating vowel-related variation in jaw and vocal fold vibrations.[3,4] The magnitude of jaw opening has been shown to be inversely related to the average fundamental frequency (F_0). There are also reports on the effect of palatal and orthognathic surgery on voice, speech, and velopharyngeal status.[4–9] Jorge et al has reported on the influence of orthognathic surgery on the F_0 in a single patient. The result of his investigation indicated that F_0 increases after surgery and corresponds to the vertical movement of the hyoid bone.[4] Only one study has explored the relationship between maxillary dental arch and voice classification. This was a pilot study on nine professional singers, evaluating the depth, length, width, and volume of the palate in relation to the different vocal registers.[10] In the same line of thoughts, Friedericke Roers had investigated the relationship between vocal tract dimensions and voice classification by examining 132 images obtained by X-ray material. Looking at the relationship between the voice classification and the total vocal tract length, the differences between most of the classifications were significant. The variations of the total vocal tract length were more dependent on the length of the pharynx cavity than on the length of the mouth cavity, defined as the upper incisor-atlas distance.[11]

The purpose of this investigation was to report on the correlation between the lateral facial skeletal cephalometric measurements and the F_0 and habitual frequency in a group of subjects presenting to the Orthodontic clinic. The hypothesis is that there is no correlation or a poor correlation between F_0 and the anteroposterior cephalometric facial skeletal

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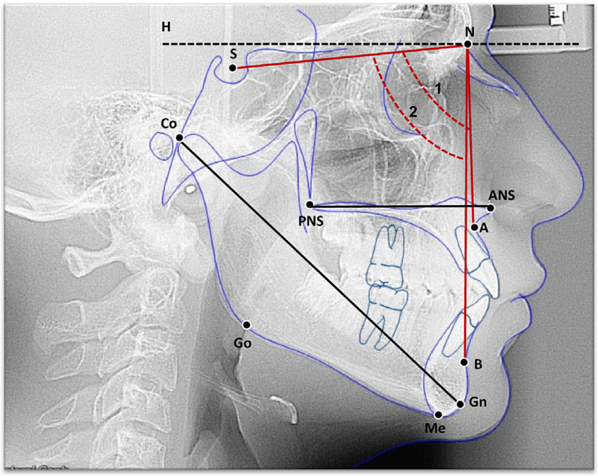

FIGURE 1. Lateral cephalometric tracing showing the landmarks and angles measured in the study. S, Sella Turcica; N, Nasion; A, deepest point on the premaxilla between anterior nasal spine and dental alveolus; B, deepest point on anterior part of the mandible; ANS, anterior nasal spine; PNS, posterior nasal spine; Co, Condylion, antero-superior point of the condyle; Gn, Gnathion, midpoint between the most protruded and the lowest points of the symphysis. Go, Gonion, external angle of the mandible, bisecting the angle formed by tangents to the posterior border of the ramus and the inferior border of the mandible; Me, Menton, most inferior point on the symphysis of the mandible. SNA (1) and SNB (2) angles, position of the maxilla and the mandible relative to the anterior cranial base in the sagittal plane; ANB angle, indicates interjaws relationship and is computed by subtraction of SNA and SNB; ANS-PNS, maxillary length; Co-Gn, mandibular length; H, True Horizontal.

measurements. This is in line with the results of numerous reports in the literature indicating the lack of correlation between the F_0 and body size and shape.[12–15]

MATERIALS AND METHODS

A total of 45 patients (33 females and 12 males) aged between 9.3 and 36 years presenting for the first time to the Division of Orthodontics and Dentofacial Orthopedics, at the American University of Beirut Medical Center (AUBMC), were invited to participate in this study. All patients have read and signed the informed consent approved by the Institution review board. Patients with congenital facial malformations, namely cleft lip, cleft palate, and hemifacial microsomia and patients with prior history of orthodontic manipulation, treatment, or orthognatic surgery were excluded from the study. Patients with recent history of respiratory tract infection, laryngeal manipulation, or dypshonia at the time of presentation were also excluded from this study.

Dysphonia was perceived by the speech-language pathologist (senior faculty with master's degree in speech-language pathology and more than 10 years of experience) as change in voice quality, timbre, pitch, or loudness.

Before the initiation of any orthodontic treatment, a set of records was taken for every patient namely lateral cephalographs using the digital cephalostat (GE, Instrumentarium, Tuusula, Finland) in a standardized fashion and in natural head position[16] or true Horizontal (H). The following landmarks (Figure 1) were digitized on the radiograph: S: Sella Turcica; N: Nasion; A: deepest point on the premaxilla between anterior nasal spine and dental alveolus; B: deepest point on anterior part of the mandible; ANS: anterior nasal spine; PNS: posterior nasal spine; CO: Condylion, antero-superior point of the condyle; GN: Gnathion, midpoint between the most protruded and the lowest points of the symphysis; GO: Gonion, external angle of the mandible, bisecting the angle formed by tangents to the posterior border of the ramus and the inferior border of the mandible; and Me: Menton, most inferior point on the symphysis of the mandible.

Consequently, angular and linear measurements were computed to evaluate the sagittal positions of the maxilla and the mandible relative to the cranial base and to each other. Angular measurement included: SNA angle that reflects the sagittal position of the maxilla relative to the anterior cranial base. This angle is defined by two lines, the line joining Sella tursica S to Nasion N and the line joining the Nasion N to the deepest point on the premaxilla A. Angle SNB reflects the sagittal position of the mandible and is defined by two lines, the line joining the Sella tursica S to Nasion N and the line

TABLE 1.
Descriptive Statistics of the Anteroposterior Cephalometric Measurements in Both the Total Group (N = 45) Before and After Excluding the Pubertal Subjects (N = 23)

Sagital Progression and Length of Upper and Lower Jaws	Total Group of Subjects (N = 45)		Total Excluding the Pubertal Subjects (N = 23)	
	Mean ± SD	Range	Mean ± SD	Range
Position (SNA*)	80.753 ± 3.2016	74.0–91.0	80.557 ± 2.068	75.0–83.8
Position (SNB*)	77.409 ± 3.6427	69.5–87.0	76.635 ± 2.397	71.3–81.0
ANB*	3.336 ± 2.5763	−3.6 to 8.3	3.9 ± 2.383	−1.0 to 8.3
Length (Co-Gn*)	104.287 ± 7.9411	86.0–126.0	103.165 ± 9.043	86.0–126.0
Length (ANS-PNS*)	50.291 ± 3.9456	41.0–59.3	50.269 ± 4.589	41.0–59.3

Abbreviation: SD, standard deviation.
* SNA reflects the sagittal position of the maxilla relative to cranial base; SNB reflects the sagittal position of the mandible relative to the cranial base; ANB reflects the position of the upper and lower jaws in relation to each other; Length (CO-GN), length of the mandible; Length ANS-PNS, length of the maxilla.

joining the Nasion N to the deepest point on anterior part of the mandible B. The ANB angle referred to as subspinal-nasion-supramental angle reflects the position of the upper and lower jaws in relation to each others. Linear measurements included the following: (1) the length of the mandible (Co-Gn) measured by the distance from condyle-Co to the most anterior part of the chin referred to as gnathion-Gn and (2) the length of the maxilla (ANS-PNS) measured from anterior nasal spine-ANS to posterior nasal spine-PNS (Figure 1).

All subjects underwent acoustic analysis using Visi-Pitch IV (model 3300; KayPENTAX, Montvale, NJ) between 2 and 5 PM to minimize the time influence and daily variations on the acoustic measurements. Although the patient is seated in a quiet office, the patient's vocal signal was recorded directly into the system using a condenser microphone (SHURE SM 48, coupled to the KayPENTAX Visi-Pitch IV 3950B) at a distance of 15 cm from the mouth. The average F_0 was measured by asking the subject to sustain the vowel "ah" for 2 seconds at a comfortable pitch and loudness. The habitual frequency was measured by asking the subject to count to 10 in a normal voice.

Descriptive statistics were used to describe the cephalometric measurements and acoustic variables in the total group before and after excluding the pubertal subjects (females, 11–15.5; males, 12–16).[17] Linear regressions model was used to report R as a measure of correlation between the dependent variables F_0 and habitual frequency and the independent variables SNA, SNB, ANB, Co-Gn, and ANS-PNS.

A P-value <0.05 was considered as significant. Analyses were performed using *Statistical Analysis Package for Social Sciences* (*SPSS*, Version 19.0; SPSS, Chicago, IL).

RESULTS

Demographic data

Twelve males and 33 females participated in this study. The age ranged between 9.3 and 36 years with a mean of 15.4 ± 7.079 years. The mean age for males was 13.5 ± 6.614 years and the mean age for females was16.1 ± 7.216 years. The pubertal group consisted of 23 subjects. The mean age of the prepubertal group was 17.162 ± 9.354.

Cephalometric measures in the total group before and after excluding the pubertal subjects

In the total group, the means for SNA, SNB, and ANB were 80.753 ± 3.20, 77.409 ± 3.64, and 3.336 ± 2.57, respectively. The mean length of the mandible and maxilla were 104.28 + 7.94 mm and 50.29 + 3.94 mm, respectively. In the total group after excluding the pubertal group, the means for SNA, SNB, and ANB were 80.557 ± 2.068, 76.635 ± 2.397, and 3.9 ± 2.383, respectively. The length of the mandible and the length of the maxilla were 103.165 ± 9.043 and 50.269 ± 4.589, respectively (Table 1).

Average F_0 and habitual frequency in the total group before and after excluding the pubertal subjects

The F_0 for the whole group before was 220.75 ± 40.156 Hz and the mean habitual frequency for the whole group was

TABLE 2.
Descriptive Statistics of the F_0 and Habitual Frequencies in Both the Total Group of Subjects (N = 45) Before and After Excluding the Pubertal Subjects (N = 23)

Acoustic	Total Group of Subjects (N = 45)				Total Excluding the Pubertal Subjects (N = 23)			
	Males		Females		Males		Females	
Parameters	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
F_0 (Hz)	203.634 ± 56.742	116.723–289.650	229.3185 ± 25.783	180.897–279.813	226.817 ± 62.115	116.723–289.650	222.236 ± 33.437	136.808–273.491
Habitual frequency	194.639 ± 58.279	104.73–282.07	228.168 ± 30.068	171.74–281.31	222.461 ± 63.282	104.73–282.07	220.890 ± 42.867	123.610–275.740

Abbreviation: SD, standard deviation.

TABLE 3.
Correlation Between F_0 and Habitual Frequency and Anteroposterior Cephalometric Measures in the Total Group (N = 45) Before and After Excluding the Prepubertal Subjects (N = 23)

Sagital Projection and Length of Upper and Lower jaws	Total Subjects (N = 45)				Total Subjects Excluding Pubertal Group (N = 23)			
	F_0 (Hz)		Habitual Frequency		F_0 (Hz)		Habitual Frequency	
	R	*P* Value	*R*	*P* Value	*R*	*P* Value	*R*	*P* Value
SNA	−0.085	0.579	−0.079	0.607	−0.064	0.772	0.002	0.992
SNB	−0.098	0.523	−0.151	0.323	−0.043	0.847	−0.104	0.637
ANB	0.032	0.834	0.119	0.436	−0.012	0.955	0.115	0.601
Co-Gn	−0.528	<0.05*	−0.577	<0.05*	−0.642	0.001*	−0.688	<0.05*
ANS-PNS	−0.473	0.001*	−0.519	<0.05*	−0.472	0.023*	−0.5	0.015*

* Statistically significant (*P* value < 0.05).

216.99 ± 43.9 Hz. The means F_0 and habitual frequency for males were 203.634 ± 56.742 and 194.639 ± 58.279, respectively. The means F_0 and habitual frequency for females were 229.318 ± 25.783 and 228.168 ± 30.068, respectively.

After excluding the pubertal group, the F_0 and habitual frequency in males were 226.817 ± 62.115 and 222.461 ± 63.282, respectively, and in females, the mean F_0 and habitual frequency were 222.236 ± 33.437 and 220.890 ± 42.867, respectively (Table 2).

Correlation between the F_0 and habitual frequency and cephalometric measures in the total group before and after excluding the pubertal subjects

In the total group, there was a moderate negative correlation between F_0 and habitual frequency and the length of the mandible ($r = -0.528$ and -0.577, respectively). There was also a moderate negative correlation between F_0 and habitual frequency and the length of the maxilla ($r = -0.473$ and -0.519, respectively). Similar findings were present after excluding the pubertal subjects. With respect to the other cephalometric measurements, the correlation was poor (r value < 0.3) (Table 3).

Correlation between F_0 and habitual frequency and cephalometric measures in females and males

When subjects were stratified by gender, there was still a moderate negative correlation between average F_0 and habitual pitch and length of the upper and lower jaws in males. In the female group, there was also a moderate negative correlation between the habitual frequency and the length of the mandible and maxilla (Table 4).

Correlation between acoustic parameters and cephalometric measures in prepubertal group and postpubertal group

Looking at the prepubertal group that consisted of 10 subjects (age <11 years), there was no or poor correlation between any of the acoustic parameters (F_0 and habitual frequency) with the length of the mandible Co-Gn and length of the maxilla (ANS-PNS). In the postpubertal group (age >16 years), there was a negative moderate correlation between F_0 and habitual frequency, and the length of the mandible (Co-Gn) with an r value of -0.629 and -0.642, respectively (Table 5).

DISCUSSION

F_0 is one of the main components to voice. It has been reported to carry information on the emotion, attitude, and social status of the speaker.[18–20] No previous study has examined the correlation between the length and sagittal projection of the upper and lower jaw and F_0. Does the anterior projection of the mandible and maxilla correlate with the F_0 and habitual frequency? The results of this investigation indicate that in subjects aged between 9 and 36 years, there is a moderate negative correlation ($0.3 < r < 0.7$) between the F_0 and habitual frequency and the length of the mandible and maxilla. Both the F_0 and habitual frequency tend to be lower

TABLE 4.
Correlation Between Acoustic Parameters and Cephalometric Measures in Males and Females

Length of Upper and Lower Jaws	Males				Females			
	F_0 (Hz)		Habitual Pitch		F_0 (Hz)		Habitual Pitch	
	R	*P* Value	*R*	*P* Value	R	*P* Value	*R*	*P* Value
Co-Gn	−0.691	0.013*	−0.682	0.015*	−0.337	0.055	−0.450	0.009*
ANS-PNS	−0.637	0.026*	−0.591	0.043*	−0.315	0.074	−0.426	0.014*

* Statistically significant (*P* value < 0.05).

TABLE 5.
Correlation Between F_0 and Habitual Frequency and Cephalometric Measures in the Prepubertal and Postpubertal Group

	Subjects Aged < 11 y				Subjects Aged > 16 y			
	F_0 (Hz)		Habitual Frequency (Hz)		F_0 (Hz)		Habitual Frequency (Hz)	
Length of Upper and Lower Jaws	*R*	*P* Value	*R*	*P* Value	*R*	*P* Value	*R*	*P* Value
Co-Gn	−0.036	0.922	0.071	0.846	−0.629	0.021*	−0.642	0.018*
ANS-PNS	−0.05	0.892	−0.212	0.556	−0.353	0.237	−0.3	0.32

* Statistically significant (*P* value < 0.05).

in subjects who have higher CCo-Gn and PNS-ANS values compared with those with lower values. This was also true when we have excluded the pubertal subjects. Even when stratified by gender, the results still indicate the same findings, more so in males compared with females, as evident by having both the F_0 and habitual frequency negatively correlating with the length of both the upper and lower jaws versus having only the habitual frequency correlating with the length of the mandible and maxilla in females. Similarly in the total group after excluding the pubertal subjects, there was a significant correlation between the length of the mandible and maxilla and the F_0 and habitual frequency.

This negative moderate correlation between the F_0 and length of the mandible and maxilla, more so in males, can be explained hypothetically on the parallel growth of both the facial bones and vocal folds. With growth, changes in the total body proportions follow a general axis of growth from the head to the extremities. This pattern of growth applies to the anterior relationship between the jaws, whereby at birth, the mandible is generally retrognathic in relation to the maxilla and the head. This relationship tends to be more harmonious over the years by a "catch up" of a forward mandibular growth leading to an orthognathic relationship between the jaws.[21–28] This growth of both the upper and lower jaws is represented by the length of the upper and lower jaw, Co-Gn, PNS-ANS, and the sagittal position of these jaws, namely SNA, SNB, and ANB. Similar to the facial bones, laryngeal growth is also dependent on the overall body growth pattern which is markedly affected by the hormonal climate of the individual. Kahane[29] in corroboration with the results of previous reports has demonstrated enlargement of the vocal folds at puberty by 63% in males and by 34% in females. The correlation between the vocal changes and size of the vocal folds has been based on the physiological impact of growth and sex hormones on the larynx, with numerous studies indicating that the larynx is a hormonal target.[30,31] As a result of the laryngeal growth, there are alterations in the mass and length of the vocal folds, with subsequent deepening of the voice. Because the F_0 and habitual frequency are primarily determined by the mass and length of the vocal folds, both of which increase in parallel with the growth of the facial bones, one would hypothetically anticipate that the length of the mandible and maxilla would correlate negatively with the aforementioned acoustic parameters. This is in accordance with the results of the investigation of Marunick and Menaldi.[10] Their data on the relationship between palatal dimensions and vocal registers suggested that sopranos have a shallow palate (17–18 mm), whereas mezzo-sopranos have a medium palate (19–20 mm) and altos had a deep palate (21–22 mm).

On the other hand, the presence of a moderate rather than a strong correlation between facial skeletal measurements and both the F_0 and habitual frequencies in our study corroborates partially previous reports in the literature indicating no correlation between body size and shape and F_0 in human. Despite the fact that the length and mass of the vocal folds are major determinants of the F_0 and habitual frequency, the overall body and facial size seem to have little effect on these acoustic parameters. Lass and Brown[32] in their analysis of 30 recordings to determine the relationship between speaker's heights, weights, body surface, and speaking F_0 have indicated no significant correlation. Kunzel[14] in his attempt to shed further light on this issue, he investigated the correlation between the F_0 and individual height and weight of 105 males and 78 female subjects. His results indicated no correlation either. A study by Collins[12] also revealed no relationship between F_0 and any of the body physical measures. Similarly, a study by Van Dommelen and Moxness[13] revealed that listener could not predict the weight and height of speaker by using their F_0 and formants and only speech rate correlated with speaker body dimensions in males. The authors of this manuscript have also analyzed the correlation between the F_0 and body height, weight, and fat distribution in 40 male subjects. The results showed no significant correlation between the acoustic parameter, F_0, and any of the body variables.

This study has three limitations: One is the relatively small number of subjects and the heterogeneity in the age group. A future investigation on a larger group of adult subjects will be more indicative of the correlation between the length of the upper and lower jaws and F_0. A second limitation is the lack of data on the length of the vocal tract and/or vocal folds. The presence of these measurements would have substantiated the aforementioned correlation. Last but not the least is the impact of social, psychological, and functional factors on the average F_0 and habitual F_0. These factors were not accounted for in this investigation.

CONCLUSION

There is a moderate negative correlation between the length of the upper and lower jaw and the average F_0 and habitual frequency. The remaining facial sagittal projection parameters do not correlate with the average F_0 and habitual frequency.

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