Correlation Between the Position of the Hyoid Bone on Lateral Cephalographs and Formant Frequencies

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Summary: Objectives. The objective of this study is to examine the F1, F2, F3, and F4 during sustained vowels /ɑ/, /i/, /o/, /u/.
Study Design. Prospective cross-sectional study.
Methods. Fifty-two consecutive patients aged between 9 years and 38 years were invited to participate in this study. Linear measurements included linear vertical distance from the hyoid bone to the sella turcica (H-S); linear vertical distance from the hyoid bone to the posterior nasal spine (H-PNS); linear measure from the hyoid bone to the most anterior point of the cervical vertebra C3 (H-C3); and linear vertical distance from the hyoid bone to the mandibular plane (H-MP).
Results. The results showed a moderate and statistically significant correlation between the average fundamental frequency for the vowel /ɑ/ and H-C3, H-S, and H-PNS and another moderate negative correlation between F3 and F4, and the vertical position of the hyoid bone H-C3 and H-S. For the vowel /i/, there was a moderate negative correlation between F1, F3, and F4 and H-S and also a moderate negative correlation between F3 and F4 and H-C3. For the vowel /o/, there was a moderate negative correlation between F4 and H-S and H-PNS. For the vowel /u/, only F4 correlated significantly with H-S.
Conclusion. There is a moderate correlation between the high formants, mostly F4, and the cephalo-caudal position of the hyoid bone.
Key Words: Formants–Hyoid bone–Lateral Cephalograph–Vowel–Pitch.

INTRODUCTION

The vocal tract plays an important role in vocal tract resonance. It starts with the lips and extends to the glottis, spanning the oral, pharyngeal, and laryngeal cavities. Its length and configuration are major determinants of many acoustic properties, among which are formant frequencies. Several studies have used imaging techniques to examine the morphological changes of the vocal tract in relation to voice. Most of these are either reports on the development of the human larynx or reports on vocal tract configuration in relation to speech and different vocal registers.[1–4] Using conventional X-ray or magnetic resonance imaging (MRI), vocal registers were analyzed in relation to the vocal tract dimensions, namely length and form. Marunick and Menaldi investigated the different vocal registers in female singers in relation to the maxillary dental arch. Their results indicated that sopranos, compared with mezzo-sopranos and altos, had shallower palates.[5] Echternach et al have used magnetic resonance images to measure lip opening, jaw position, pharyngeal constriction, and/or laryngeal height among others in relation to male alto and female registers.[6] Sulter et al have used spatial configuration of the vocal tract by MRI using direct and indirect methods to determine vocal tract dimensions.[7] In their study on voice classification and vocal tract dimensions in singers, Roers et al examined X-ray materials of 132 subjects. Different anatomical landmarks were used, such as the upper incisors, atlas, and glottis, and different linear measurements were used to measure the length of the vocal tract, namely the oral, velar, and pharyngeal lines.[8]

In all the aforementioned reports, acoustic properties were analyzed in relation to the length and configuration of the vocal tract with no reference to the hyoid bone position, which is an important anatomical landmark used in vocal pedagogy and in the clinical assessment of patients with voice disorders. Only few studies have radiologically examined the correlation between F0 using the hyoid bone as a radiologic landmark.[9,10] In all these studies, the position of the hyoid bone was investigated in relation to changes in the vocal frequency. In a cross-sectional study of 10 subjects, humming and pitch in relation to the craniofacial/cervical morphology were assessed by Miller et al using MRI.[9] The results indicated the significant effect of note conditions in 27% of the measurements. There was an increase in the craniocervical angles, a rise in the laryngeal and hyoid bone positions in relation to the cranial base, and an increase in the sternum hyoid distance with humming of the high notes. The relationship between laryngeal vertical movement and changes in vocal frequency (F0) has also been investigated by Honda et al.[10] Changes in F0 were coupled with vertical movement of the larynx and lordosis of the cervical spine. Movement of the larynx in the vertical direction results in the rotation of the cricoid cartilage and subsequent tensioning of the vocal folds. MRI results from Honda et al's study indicated that vertical movement of the larynx comprises an effective F0-lowering mechanism.

The purpose of the present study is to provide more insights into the correlation between the position of the hyoid bone and formant frequencies F1, F2, F3, and F4 during sustained vowels

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/ɑ/, /i/, /o/, /u/ using lateral cephalometric measurements in a group of subjects presenting to the orthodontic service.

PATIENTS AND METHODS

Participants

A total of 52 consecutive patients between the ages of 9 years and 38 years presenting for the first time to the division of Orthodontics and Dentofacial Orthopedics at the American University of Beirut Medical Center were invited to participate in this study. Patients with history of orthodontic manipulation, treatment, or orthognathic surgery, as well as patients with congenital facial malformations, namely cleft lip and palate and hemi-facial microsomia, were excluded. Patients with recent history of respiratory tract infection and/or laryngeal manipulation were excluded from the study. Patients with dysphonia as perceived by a senior speech language pathologist at the time of presentation were also excluded from this study. All participants have read and signed the informed consent form approved by the institutional review board.

Materials and procedures

A set of records was taken for every patient, namely lateral cephalographs, using a digital cephalostat (GE, Instrumentarium, Tuusula, Finland) in a standardized fashion and with the head of the patient in natural position. The following landmarks were employed on a lateral cephalometric radiograph: H: most anterior point of the hyoid; S: midpoint of sella tursica; PNS: posterior nasal spine, the spine-like projection from the posterosuperior midline of the horizontal plate of the palatine bone; C3: third cervical vertebra; Go: gonion, a spine-like projection from the posterosuperior midline of the horizontal plate of the palatine bone; Me: menton, the most inferior point on the chin; MP: mandibular plane; V: vertebra. After that, linear measurements were obtained: H-S: linear vertical distance from H to S; H-PNS: linear vertical distance from H to PNS; H-C3: linear measure from H to the most anterior point of C3; H-MP: linear vertical distance from H to MP (Figure 1).

All subjects underwent acoustic analysis using Visi-Pitch IV (Model 3300, KayPENTAX, Montvale, New Jersey), and the average fundamental frequency and habitual frequency were reported. Formant frequencies across F1, F2, F3, and F4 were determined using the Real-Time Spectrogram of VP 3950 (Sona-Speech 2, Model 3650, KayPENTAX). The Sono Match module, using the Real-Time FFT window, was used to confirm the results obtained by the Real-Time Spectrogram. The cursor was placed at the centermost point of the steady-state formant band when looking at the spectrogram. The formants were visually identified, after which the cursor was placed in the middle of the formant's horizontal lines and the value was computed and given.

The mean, standard deviation, and value range were derived for all variables for statistical analyses. Pearson's correlation was calculated to estimate the strength of the relationship between the measurement parameters of the hyoid cartilage and acoustic parameters. We conducted our statistical analyses using *SPSS* Statistics 21 (IBM, Armonk, New York). Statistical significance was set at *P*-values of <0.05 and <0.01.

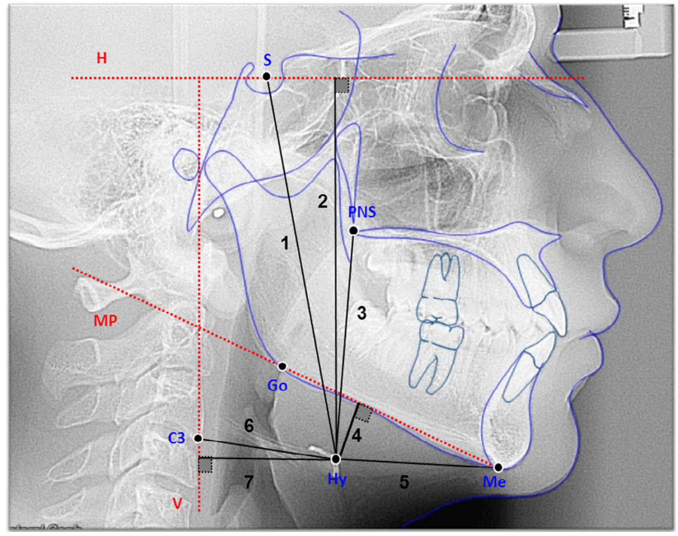

FIGURE 1. The figure shows the landmarks that were employed on a lateral cephalometric radiograph: H: most anterior point of the hyoid; S: midpoint of the sella tursica; posterior nasal spine (PNS): the spine-like projection from the posterosuperior midline of the horizontal plate of the palatine bone;C3: third cervical vertebra; gonion (Go): spine-like projection from the posterosuperior midline of the horizontal plate of the palatine bone; menton (Me): the most inferior point on the chin;MP: mandibular plane; V: vertebra. After that, linear measurements were obtained: H-S: linear vertical distance from H to S; H-PNS: linear vertical distance from H to PNS; H-C3: linear measure from H to the most anterior point of C3; H-MP: linear vertical distance from H to MP.

RESULTS

Demographic data and means of hyoid bone parameters H-C3, H-S, H-PNS, and H-MP

The mean age of the subjects was 17.07 ± 7.20 years with 26.9% being males. The means of the four hyoid bone position parameters are as follows: H-S (mm): 92.81 ± 8.213; H-PNS (mm): 54.62 ± 6.234; H-C3 (mm): 31.6 ± 4.447; and H-MP (mm): 12.52 ± 4.692.

Means of formant frequencies for vowels /ɑ/, /i/, /o/, and /u/

The means of formants F1, F2, F3, and F4 for the vowel /ɑ/ are 836.38 Hz, 1479.42 Hz, 3105.85 Hz, and 3995.27 Hz, respectively. The means of formants F1, F2, F3, and F4 for the remaining vowels /i/, /o/, and /u/ are shown in Table 1.

Correlation between hyoid bone position and formant frequencies F1–F4 for vowels /ɑ/, /i/, /o/, and /u/ in the total group

There was a moderate correlation that was statistically significant between the average fundamental frequency for the vowel /ɑ/ and all the three cephalo-caudal parameters for the hyoid position, namely H-S, H-PNS, and H-C3 (r values of 0.596, 0.445, and 0.481, respectively with *P*-values of 0, 0.001, and 0, respectively as shown in Table 2).