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Influence of Craniofacial Morphology on Hyoid Movement: A Preliminary Correlational Study

Ronald Dubner and Keith A. Mays

Abstract

There has been little attention given to the relationship between variations in normal craniofacial morphology and swallowing physiology. This preliminary investigation evaluated the relationship between the Frankfort Mandibular Plane Angle (FMA) and hyoid displacement during swallowing. Hyoid movement was evaluated during 12-ml and 24-ml swallows of liquid barium in 12 healthy subjects (aged 20 to 29 years, median 23 years). Lateral projection videofluorography was utilized. Positions of the hyoid at maximum forward displacement, maximum upward displacement, start position, and ending position were determined using image analysis software. The mean FMA was $28.92^\circ \pm 4.08^\circ$ (mean $\pm$ SD, range 20 to 34). A Pearson Correlation (≤ 0.05) demonstrated that hyoid forward displacement was significantly inversely correlated with the FMA ($R = -.68$, $P = 0.015$ (12-ml) and $R = -.72$, $P = 0.009$ (24-ml)); thus the greater the FMA, the smaller was the hyoid forward displacement. Upward displacement of the hyoid was not significantly correlated with FMA for 12-ml ($R = -0.41$, $P = 0.55$) or 24-ml swallows ($R = 0.21$, $P = 0.512$). Additionally, there was no significant correlation between hyoid starting or ending positions. In conclusion, the results of this preliminary study suggest that normal variations in morphology, as measured by the FMA, may influence hyoid movement and therefore affect the swallowing physiology.

Keywords

Stomatognathic system; Hyoid bone; Mandible; Deglutition; Fluoroscopy; Mandibular rest position

Introduction

Videofluorographic swallowing studies (VFSS) are commonly utilized to evaluate the oral and pharyngeal stages of swallowing [1]. Patients are asked to swallow barium preparations of various consistencies during VFSS. This allows for evaluation of movement, bolus propulsion, airway protection and other parameters [2,3]. One critical element is the displacement of the hyoid bone, which moves forward and upward during swallowing. Using image analysis software one can measure and track the displacement of the hyoid bone during swallowing.

The “U”-shaped hyoid bone is suspended by a muscular sling made up of the suprahyoid muscles. [4, 5]. The hyoid displacement is produced by contraction of the suprahyoid musculature that produces an upward and forward movement that is accompanied by a relaxation of the cricopharyngeus muscle [6]. This synergistic contraction and relaxation facilitates displacement of the hyoid bone and tongue, pulls the larynx forward and upward, and opens the upper esophageal sphincter (UES), permitting a bolus to enter the esophagus [7, 8, 9, 2, 6]. The concurrent suprahyoid muscle contraction, hyoid and tongue displacement, and

UES opening are accompanied by the sealing of the larynx, all of which are essential for safe swallowing.

The suprahyoid muscles are attached to several craniofacial landmarks, such as the mandibular symphysis, the inferior border of the mandible, and the base of the skull, as well as the tongue. Therefore, specific elements of swallowing such as tongue movement and hyoid movement may be affected by craniofacial morphology. Fujiki, et al [10], demonstrated that there was a significant correlation between the mandibular plane position, ramus height, anteroposterior dimension of the maxilla and tongue tip movement during swallowing in female subjects with anterior open bites. Cheng et al [11] used real time B-mode (two dimensional static imaging) plus M mode (two dimensional motion detection mode) ultrasonography and demonstrated that craniofacial morphology was significantly correlated with tongue movement during swallowing. Cuzzo et al [12] used cineradiography to evaluate the effect on swallowing of an orthodontic crib appliance that restrained the tongue posteriorly. It was determined that the hyoid was positioned posteriorly and inferiorly in subjects with an initial hyoid position closer to the mandibular plane. These studies support the idea that normal variations in craniofacial morphology can affect the kinesiology of swallowing.

Ishida et al. evaluated the forward and upward movement of the hyoid bone, it was determined that the forward displacement was highly consistent and had larger amplitude than upward displacement [13]. They suggested that the upward displacement was related to oral cavity events, and the forward displacement to pharyngeal processes. Gay et al. evaluated swallowing function with and without bite blocks placed between the molars [14]. With the bite blocks in place the tongue movement pattern differed between male and female subjects. Gay inferred that this tongue pattern difference might be due to the larger mandible of the male, and that morphology may play a role in the motor control strategy for swallowing. Functionally speaking there is a relationship between the hyoid, the tongue, and the mandible in regards to swallowing function. These findings suggest that, normal anatomical variations in craniofacial morphology, particularly variations in the size and position of the mandible could affect tongue movement in swallowing. One possible mechanism for this would be alteration in the pattern of hyoid movement, since the tongue and hyoid are connected.

Craniofacial morphology (CM) can be described by determining the relationships among anatomic features of the cranium and neighboring structures. One way to describe CM is the relationship between the Frankfort Horizontal plane and other reference planes, such as the mandibular plane [15, 16, 10]. The Frankfort Horizontal plane is an imaginary craniofacial plane passing through the inferior orbital rims and the superior borders of the external auditory meati; it defines the horizontal plane of the head. The mandibular plane is the plane passing through the inferior border of the body of the mandible. The Frankfort – Mandibular plane angle (FMA) is formed by the intersection of the Frankfort Horizontal plane and the mandibular plane. Hocevar and Stewart reported that the FMA was highly correlated with other measures of CM, and so we chose this method for classifying CM in the present study [16].

The purpose of this investigation was to determine the relationship between the Frankfort Mandibular Plane Angle (FMA) and hyoid bone displacement during liquid swallowing. We hypothesized that the FMA would be correlated with hyoid movement since the hyoid bone is attached to the mandible by the suprahyoid musculature.

Materials and Methods

Subjects

This retrospective study used a convenience sample from the Oral Function and Swallowing research database at Johns Hopkins University. Written and oral informed consent was

obtained from subjects as per our institutional review board prior to dental examination and VFSS. Videofluorographic swallowing studies were performed on these subjects as part of an ongoing project on the physiology of swallowing. Twelve healthy adults (7 males, 5 females aged 20 to 29 years with a median age of 23 years) were included in this study. Each patient was evaluated medically and had no history of dysphagia, jaw pain, gastroesophageal reflux disease, serious medical conditions, or head and neck trauma. Subjects also underwent dental evaluations. All subjects had class I dental occlusion, and there was no dental pathology noted.

Data Collection—A standard videofluoroscopic apparatus was utilized including S-VHS VCR, microphone and video timer. Prior to fluoroscopy, 1 mm lead markers were cut from a lead sheet (Goodfellow, Malvern, PA) with a standard hole punch, and cemented to the buccal surface of upper and lower left canines and first molars near the gingival margin using Ketac Cem (Ketac, ESPE-Premier Sales Corp., Norristown, PA). The lead marker acts as a radiopaque reference during VFSS, and facilitates the establishment of X and Y coordinates and the maxillary occlusal plane during data reduction, as described previously [13].

Subjects were seated comfortably in a chair in the appropriate position for lateral projection radiographic imaging. The image intensifier was held at a fixed distance from the X-ray tube. The magnification mode of the fluoroscope was not used. Video output was recorded using an S-VHS videocassette recorder at 30 frames per second. A video timer (VTG-33, Tokyo, Japan) added a time signal to each frame of the video recording in 0.01 s increments.

Videofluorographic (VFG) recordings were made of each subject swallowing 12-ml and 24-ml boluses of liquid barium contrast (EZ Paque 96% w/w) as well as solid food with barium. Only the liquid swallows were analyzed for the present study. The barium solution was mixed and then placed in an appropriate syringe. The solution was injected into the subject's mouth. Once the subject had received the entire bolus he/she was instructed to swallow. VFG recording was started as the barium solution was introduced into the patient's mouth and the recording ended after the swallow. VFG protocol and technique were described previously [17, 1].

Data Reduction—Each subject's craniofacial morphology (CM) was determined after the VFG studies were completed by marking the positions of specific anatomic landmarks onto orthodontic tracing paper placed on the video monitor. All tracings and measurements were made by one investigator (K.M.). The videotapes were reviewed, and one frame with the jaw in position of maximum intercuspation, and the head in true lateral projection, was selected for each subject. The FMA was then determined by tracing lines representing the Frankfort horizontal plane and the mandibular plane and measuring their angle of convergence (figure 1). The investigator making the craniofacial measurements was blinded to the data regarding displacement of the hyoid bone.

A frame-by-frame analysis utilizing the stop-motion capabilities of the VCR was used to visually evaluate each swallow. Distances were calibrated by imaging a grid of 0.5 inch squares. The hyoid bone position at maximum forward displacement, and at maximum upward displacement, at start position, and at end position were observed and measured by using digital image analysis software (SCION Image, Scion Corp., Frederick, Maryland). For purposes of this study, "horizontal" was defined by a line passing through the upper canine and molar markers, parallel to the occlusal plane. The maximum forward (FD) and upward (UD) displacements of the hyoid bone for each swallow were defined as the horizontal and vertical distances (respectively) between the hyoid ending position and position of hyoid maximum displacement. The resting position of the hyoid was defined as its ending position rather than its starting position because subjects were holding liquid in the mouth prior to swallowing, and this altered the pre-swallow position of the hyoid bone. Inter-rater reliability testing showed a mean difference of 0.02 ± 1.8 mm for the X coordinate and 0.5 ± 2.4 mm for the Y coordinate of hyoid position.

Data Analysis—The displacement of the hyoid bone was first examined with descriptive statistics: means, standard deviations, and histograms. Group differences were analyzed with T-tests. Multiple linear regression analysis was performed to evaluate the relationship between the FMA and the excursion of the hyoid bone, as well as the effect of gender on this relationship. Separate analyses were performed for vertical and horizontal displacement of the hyoid bone. Statistical procedures were performed with SPSS 11.5 (SPSS, Inc., Chicago, Ill.).

RESULTS

The mean FMA was $27.57^\circ \pm 4.16^\circ$ (mean $\pm$ SD) for males and $30.80^\circ \pm 3.49^\circ$ for females; this difference was not statistically significant (Table 1). Upward displacement of the hyoid was significantly higher for males (34 ± 2.3 mm) than females (29 ± 3.6 mm) for the 12 ml bolus only, $p = 0.005$. There was no significant difference in the mean forward displacement of the hyoid bone by gender for either the 12 ml or 24 ml bolus, or mean upward hyoid displacement for the 24 ml bolus.

There was a significant negative correlation between FMA and forward displacement of the hyoid for both the 12-ml and 24-ml bolus volumes ($R = -0.68$, $p = 0.015$ and $R = -0.75$, $p = 0.005$ respectively; Table 2). However, there was no significant correlation between the FMA and upward displacement of the hyoid for either the 12-ml or 24-ml bolus volumes ($R = -0.46$, $p = 0.13$ and $R = -0.06$, $p = 0.85$ respectively). There was no correlation between the FMA and position of the hyoid bone immediately before or after the swallow.

Two separate multiple regression analyses were performed, one for forward displacement and the other for upward displacement of the hyoid bone. Each model included FMA and volume as independent variables and gender as a dummy variable. The multiple regression revealed a significant inverse relationship between FMA and forward displacement of the hyoid bone ($\beta = -0.673$, $p = 0.001$; table 3 and figure 2). Increasing FMA was associated with decreasing forward displacement. Neither gender nor bolus volume had a significant effect on forward displacement.

There was a statistically significant inverse relationship between bolus volume and upward displacement of the hyoid bone ($\beta = -0.422$, $p = 0.043$, table 3). Upward displacement was greater for the 12 ml than the 24 ml bolus volume. However, neither FMA nor gender had a significant effect on upward displacement.

DISCUSSION

The major finding of this study is a significant negative correlation between the FMA and forward but not upward displacement of the hyoid bone during liquid barium swallows. Conversely, bolus volume had a significant effect on upward but not forward displacement of the hyoid. Forward hyoid displacement increased as the FMA decreased, and upward displacement was greater for 12ml than for 24 ml swallows. The bivariate analysis showed a significant relationship between gender and upward displacement, but this was not supported by the multivariate regression. This lack of statistical significance between genders in the multivariate regression may be due to the small sample size overall and within each group. Neither the starting nor the ending position of the hyoid was significantly correlated with FMA. This suggests that the difference in forward displacement based on FMA is a dynamic process related to swallow physiology. Importantly, these changes in swallow physiology were associated with normal variations in craniofacial morphology. This may explain some of the inter-individual variation in normal swallow response reported in numerous studies.

Gerstner et al, demonstrated that there is a quantifiable relationship between Angle's skeletal classification and masticatory function, in which oral morphology could predict oral function [18]. The findings of this study support the idea that craniofacial morphologic measurements may be used to predict oral function. In the current study the Frankfort-mandibular plane angle was correlated with forward displacement of the hyoid bone during deglutition. We suggest that the FMA may be a predictor of hyoid displacement during swallowing.

Fujiki et al [10] demonstrated a negative correlation between several aspects of craniofacial morphology and tongue movement during swallowing. The experimental group which had a greater FMA than the control group had a statistically significant relationship between the Frankfort-mandibular plane angle and tongue movement. Our findings also support the hypothesis that individuals with an higher FMA will differ in oral function during deglutition. Our investigation was limited to evaluating the hyoid movement during swallowing. However, a broader study that evaluates both tongue and hyoid movement may be warranted in order to evaluate the relationship between the overall swallowing mechanism and craniofacial morphology.

The mechanism for the observed relationships between FMA and displacement are not clear. We suggest these relationships between form and function could be due to differences in muscle length and resulting mechanical advantage. Studies have demonstrated that masseter and temporalis activity are correlated with craniofacial morphology and that there was a mechanical advantage in the jaw muscles between individuals with long verses short face syndrome [19, 20]. Individuals with higher FMA have a steeper mandibular plane and shorter mandibular ramus compared to lower FMA individuals. This means that the chin is in a lower position relative the gonial angle for a higher FMA. The lower chin position could potentially put the geniohyoid muscles in a position of mechanical disadvantage, reducing their traction on the hyoid bone during swallowing, and thereby producing a smaller forward hyoid displacement in individuals with high FMA. Differences in the position of the gonial angle and length of the mandibular ramus could have additional effects on control of hyoid motion. These phenomena deserve further study.

Muto and Kanazawa using cephalometric radiographs demonstrated that there was a significant difference in the hyoid position in relation to the chin and the mandibular plane between men and women [21]. Their findings suggest that the hyoid position is lower in males compared to females. In our study there was no correlation between hyoid movement and gender, nor did the multiple regression analysis demonstrate a significant relationship between gender and hyoid displacement in swallowing.

The clinical significance of these findings is uncertain. It is conceivable that FMA could have an indirect influence on opening of the upper esophageal sphincter (UES), since this opening is produced by contraction of the anterior suprahyoid musculature. [6, 22, 8]. Changes in the mechanics of the suprahyoid muscles may alter UES function, as shown by the improvement in UES opening with strengthening of these muscles. [23]

In this preliminary investigation the FMA was measured manually from still images on the video monitor. A prospective study using digitized lateral cephalometric radiographs and a full set of craniofacial measurements (FMA, gonial angle position, mandibular plane position, and ramus height) is warranted to confirm and extend the results reported here. Another limitation of this study was the number of swallows. In this study there were two swallowing repetitions of two different bolus volumes. Future studies should include multiple swallow with a range of bolus volumes.

CONCLUSIONS

The findings of this preliminary study demonstrated that the forward displacement of the hyoid bone during liquid swallowing was significantly related to craniofacial morphology. Specifically, as the Frankfort-mandibular plane angle increased the forward displacement of the hyoid bone decreased. We hypothesize that the observed effects may be related to the biomechanics of the suprahyoid musculature.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Figure 1. Radiograph showing the relationship between the hyoid bone and the Frankfort-mandibular plane angle (FMA) as displayed on a VFG image during swallowing.

Figure 2. Scatterplot of Frankfort-mandibular angle vs. forward displacement of the hyoid bone. A least squares regression line is shown with its equation.

Figure 3. Scatterplot of Frankfort-mandibular angle vs. upward displacement of the hyoid bone. A least squares regression line is shown with its equation.

Table 1
Effect of Gender on Hyoid Displacement. T test for independent samples

12 ml Bolus Swallow					
	Gender	N	Mean	SD	P
Forward Displacement	Male	7	57.17	5.58	.326
	Female	5	52.96	8.61	
Upward Displacement	Male	7	34.01	2.27	.005
	Female	5	28.94	2.57	
24 ml Bolus Swallow					
Forward Displacement	Male	7	14.69	4.83	.324
	Female	5	12.29	2.03	
Upward Displacement	Male	7	5.32	4.53	.900
	Female	5	5.62	2.58	

Correlation of FMA with gender, hyoid displacement, and hyoid position before and after swallow for 12 ml and 24 ml volume swallows

12 ml Bolus Swallow					
	Gender	Forward displacement	Upward displacement	Before swallow	After swallow
Pearson R	0.408	-0.678*	-0.461	-0.280	-0.122
P	.188	0.015	.131	0.378	0.706
N	12	12	12	12	12
24 ml Bolus Swallow					
	Gender	Forward displacement	Upward displacement	Before swallow	After swallow
Pearson R	0.408	-0.746**	0.060	0.0085	0.513
P	.188	0.005	0.852	0.792	0.088
N	12	12	12	12	12

* p < 0.05 level
** p < 0.01 level

Table 3

Multiple Regression analyses for forward and upward displacement of the hyoid bone (FMA=Frankfort-mandibular plane angle)

Multiple Regression -Forward Displacement			
	B	Std. Error	P
FMA	-.673	.156	.001
Gender	-.091	1.238	.598
Volume	-.088	.093	.575
Multiple Regression -Upward Displacement			
	B	Std. Error	P
FMA	-.152	.242	.486
Gender	-.133	1.913	.540
Volume	-.422	.144	.043