*Original Article*

# Heterogeneity in Vertical Positioning of the Hyoid Bone in Relation to Genioglossal Activity in Men

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**Abstract:** The aim of this study was to investigate whether there is any relationship among genioglossus (GG) baseline electromyographic (EMG) activity, upper airway resistance, and sex. We hypothesized that GG baseline EMG activity and its response to pharyngeal partial occlusion may be heterogeneous in men but homogeneous in women. Lateral head roentgenograms were obtained in the upright standing position with the head at natural posture from age-matched, healthy, 16 men and 15 women. A miniature balloon was placed in the retroglossal pharynx, and a record of GG EMG response was measured. The database was divided by sex and further categorized based on the increment of GG EMG response to inflation of the balloon. Both sexes included responsive subjects showing a greater GG EMG activity increase than the mean values and a counterpart, ie, a nonresponsive group. When the two subgroups were compared, the hyoid bone of the responsive subjects positioned more inferiorly than that of nonresponsive subjects in men ($P < .05$). When men and women were compared, most cephalometric measurements were significantly larger in the male responders, but no difference was shown in the nonresponders. We concluded that men with a lower hyoid bone show greater GG reflexive response to the partial oropharyngeal obstruction. (*Angle Orthod* 2004;74:343–348.)

**Key Words:** Cephalometrics; Genioglossus muscle; Hyoid bone; OSA

## INTRODUCTION

The human hyoid is a unique bone, ie, not articulated with other bones and suspended in the soft tissue by ligaments and muscles.[1] This bone positions above the level of the lower mandible border in early human life but with age, gradually descends to approximately the fourth cervical vertebra.[2] Because it is not articulated with other bones, the position of the hyoid bone changes with head posture, body position, and other physiologic states and moves during various oral functions in close conjunction with tongue activity.[3,4] A part of genioglossus (GG) muscle fibers is intermingled with fibers of the geniohyoid muscle, and the hyoid bone moves with the tongue and mouth floor during swallowing and respiration.[1,5,6]

The vertical position of the hyoid bone is believed to be a predictor of obstructive sleep apnea (OSA). Numerous studies have reported that the distance between the hyoid bone and the lower mandible border could be a sensitive morphological indicator of OSA.[7–9] Although use of this measurement to differentiate OSA patients from the general population has not yet been reported, it is presumably of low specificity. Considering the complex nature of the pathophysiology of OSA[10,11] and the wide range of normal facial morphology, not all men having a low hyoid bone position would be OSA patients. However, because OSA as a condition that most times begins to manifest its symptoms after middle age, it is useful to recognize a potential patient early.[12]

GG electromyographic (EMG) activity in OSA patients appears to be higher than the normal population average during wakefulness. This is probably the result of compensatory effort to maintain a patent breathing passage[13], which may be modulated by negative pharyngeal pressure[14] and airway resistance.[15] Previous studies hypothesized that this compensatory activity is associated with a low hyoid bone position in OSA patients[16,17] and suggested that whereas the muscles attached to the hyoid bone work to maintain the patency of the pharyngeal airway, the infrahyoid muscles overpower the suprahyoid muscles. Thus, an imbalance in muscle tension brings the hyoid bone downward.

We postulate that some individuals have a smaller or

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functionally less-patent pharyngeal airway than others. Thus, more work is needed to compensate, and the hyoid muscles exert an increased effort during wakefulness. We hypothesize that some young adult men would have higher genioglossal baseline activity and a stronger GG reflexive response to partial occlusion of the upper airway than others. This higher baseline EMG activity may be correlated with certain morphologic characteristics of the upper airway. This study was designed to test these hypotheses in relation to sex.

## MATERIALS AND METHODS

### Participants

Thirty-one healthy, 16 men and 15 women, volunteers were recruited. The EMG activity records were obtained during the follicular phase of the menstrual cycle from 12 of 15 females and during the placebo days for three female subjects taking oral contraceptives.[15,18–21] The placebo days were defined as a withdrawal period of contraceptive medication during for which the packet provides placebo pills. The first day of the menstrual cycle was by subject report. Volunteers subjected to orthognathic surgery, those under medication for ongoing respiratory incompetence, or those diagnosed any endocrinological disorders were excluded from the subject pool. The protocol was approved by the local Institutional Review Board.

### Cephalometric measurements

Lateral cephalograms were taken, with the subject standing with a natural head position at end expiration and not swallowing. Radiograph tracings were made by an investigator blinded to the clinical and EMG measurements. Figure 1 shows the cephalometric measurement variables.

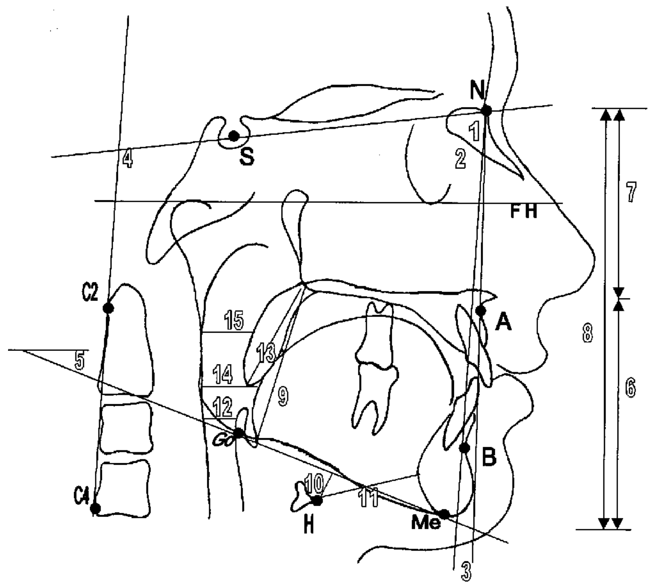


**FIGURE 1.** Cephalometric variables assessed as angular (°) and linear (mm) measurements. Used landmarks and variables are adapted from the previous publications for consistency.[9,29] (1) SNA; (2) SNB; (3) ANB; (4) SN-C4 (angle formed by SN and C2-C4); (5) MP-FH; (6) LFH; (7) UFH; (8) TFH; (9) VAL (vertical airway length, base of epiglottis to posterior nasal spine); (10) MP-H (vertical hyoid position, distance from the mandibular plane [MP] to hyoid bone [H]; (11) RGN-H (horizontal hyoid position, distance from retrognathion to H); (12) IAS (inferior airway space, base of the tongue to the posterior pharyngeal wall parallel to the line intersecting B point to gonion [Go]); (13) SPL (soft palate length, PNS to the tip of the soft palate); (14) MAS (middle airway space, base of the tongue and the posterior pharyngeal wall measured parallel to FH at the tip of the soft palate); (15) UAS (upper airway space, posterior pharyngeal wall to the soft palate measured parallel to FH at the middle of soft palate).

### EMG measurements

EMG signals were obtained using ball-type surface electrodes attached to a customized carrier made of dental impression material (Reprosil®, Densply, Milford, Del). A Pressure-Airflow-EMG data acquisition system (Persi-Sar System, version 3.0, Microtronics, Chapel Hill, NC) was used for data acquisition, conversion, storage, and analysis of the signals. Unfiltered EMG signals, sampled at the rate of 200 per second, were electronically amplified 2000 times, averaged, and rectified. Ventilation was maintained through a tight-fitting nasal flow mask in various sizes, with the mouth closed. Reference pressures and flows were monitored in the nasal mask and the oral cavity with a pneumotachometer (MT1FP no. 1, Microtronics) and differential pressure transducers (MTSP-P2F1, Microtronics) (Figure 2).

GG responses to balloon inflation were recorded during spontaneous breathing in the upright sitting position. A miniature angioplasty balloon (0.8 cm in diameter when inflated) connected to a syringe using a catheter placed in the retroglossal area after minimum topical anesthesia with 4% lidocaine applied to the uvula area was inflated. GG EMG activity was recorded at the rest position first without the balloon and then after the balloon inflation. Normalization of the ratio between balloon size and cross-sectional area of the pharynx was not attempted. To record GG EMG activity at rest, the most stable segment of the EMG signal was chosen after protrusion and swallowing tasks during spontaneous tidal breathing through the nose. The EMG record during balloon inflation was taken when the balloon was sustained at full size for three to four minutes. Experimental conditions were delivered in random order by coin flip to avoid order effects. Signals were recorded three times at each tidal breathing for 30 seconds at each task and averaged.

Magnitude of EMG signals was measured by calculating the area under the rectified signals (mV) for the measured duration, divided by seconds. GG baseline EMG activity (Figure 3) was reported as raw values in mV-sec. Standardization of EMG data was unnecessary because the data were used for subgrouping purpose and not for comparisons.

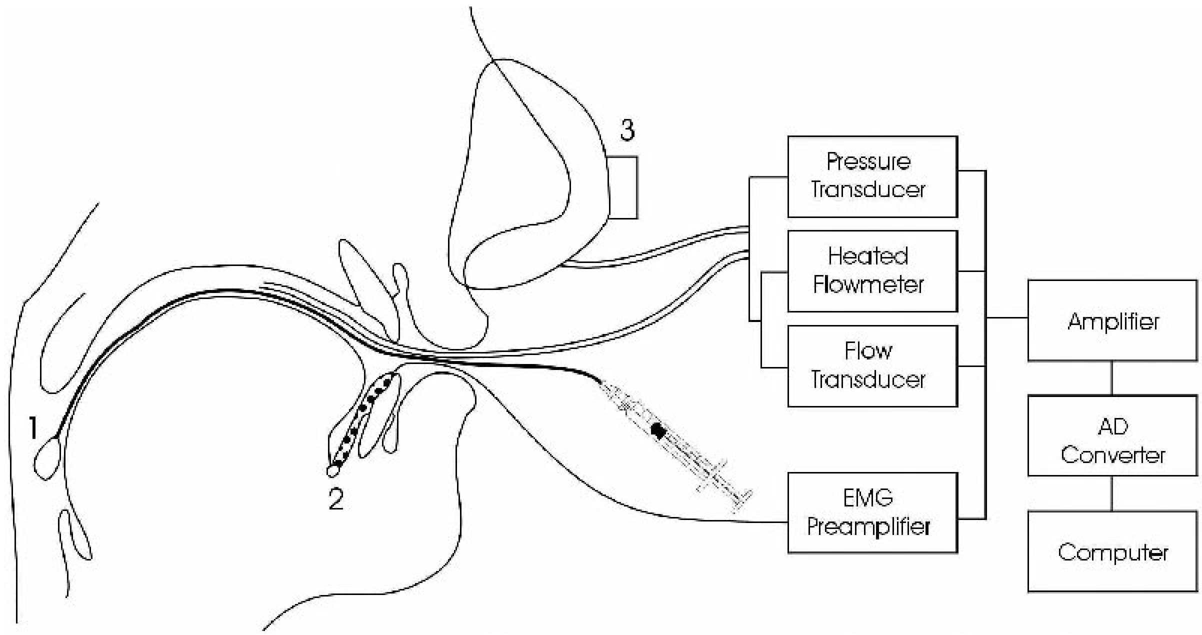


**FIGURE 2.** Schematic representation of the experimental setup. (1) A balloon is positioned in the retroglossal area of the oropharynx. The appropriate positioning of the balloon was determined by premeasured length of the catheter from the maxillary incisors on the lateral cephalogram. (2) Indicates bipolar surface electrodes placed on the mouth floor approximately 1.5 cm bilaterally from the midline and midway between the lower central incisors and sublingual fold. (3) A pressure transducer connects to the tip of a nasal mask.

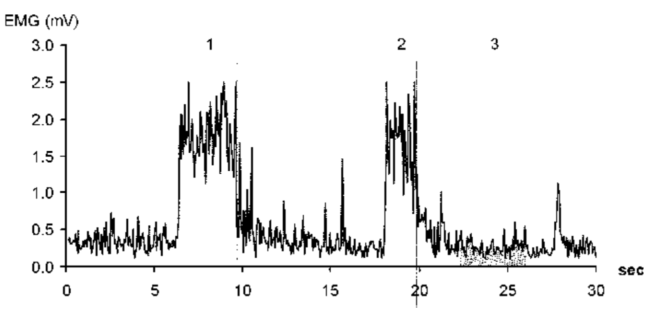


**FIGURE 3.** Typical EMG signals during maximum protrusion (1) and swallowing (2). Shaded area (3) indicates a typical basal activity of the GG muscle. Calculation of the average EMG activity, area under the signal was measured and divided by the time interval using a software. Units for the Y-axis, millivolts; X-axis, seconds.

**TABLE 1.** Cephalometric Variables by Sex

| | Mean ± SD | | |
|---|---|---|---|
| | Men (n = 16) | Women (n = 15) | *P* value |
| Age (y) | 27 ± 2.7 | 26.5 ± 3.23 | NS[a] |
| BMI (kg/m²) | 25.4 ± 2.69 | 21.0 ± 3.04 | 0.001** |
| MP-H (mm) | 15.63 ± 7.62 | 15.42 ± 7.48 | NS |
| IAS (mm) | 13.44 ± 4.68 | 11.33 ± 7.23 | NS |
| LFH (mm) | 74.13 ± 5.03 | 67.92 ± 6.78 | 0.015* |
| RGN-H (mm) | 43.94 ± 5.54 | 37.92 ± 8.72 | 0.034* |
| VAL (mm) | 78.56 ± 6.74 | 64.33 ± 19.44 | 0.011* |

[a] NS indicates not significant; * Significant at $P < .05$; ** Significant at $P < .01$.

## Statistical analysis

The database was categorized based on sex first and further stratified by the incremental GG EMG activity response to inflation of the balloon in the upright position. Both sexes included responders showing a significant GG activity increase and a nonresponsive group (nonresponders). The Student's unpaired *t*-test and the nonparametric Mann-Whitney *U*-test were used to evaluate the two-group difference (SPSS 10.0, Chicago, Ill). A *P* value less than 5% was considered significant.

# RESULTS

## Male pooled vs female pooled

The mean age of the male participants (n = 16) was 27 years with a standard deviation of 2.73 years, whereas that of the female subjects (n = 15) was 26.5 years with a standard deviation of 3.23 years. The body mass index (BMI = weight [kg]/height$^2$ [m]) for males was 25.4 with a standard deviation of 2.69 and for females was 21.2 with a standard deviation of 3.04. When male and female subjects were compared, a significant sex difference in BMI (male 25.4 vs female 21.1 at $P < .01$) was evident. Summary anthropometric data and cephalometric data are displayed in Table 1.

## Responders vs nonresponders within the same sex

The cephalometric variables were evaluated by subgroup using the GG EMG data response to the partial airway occlusion in the upright position. Responders were defined as individuals who demonstrated an EMG activity increase of

**TABLE 2.** Comparisons Within Sex for Responders vs Nonresponders[a]

| Variables | Mean ± SD | | | |
|---|---|---|---|---|
| | Men (n = 16) | | Women (n = 15) | |
| | Responders (n = 6) | Nonresponders (n = 10) | Responders (n = 5) | Nonresponders (n = 10) |
| GG EMG with balloon inflated (mVs) | 0.63 ± 2.74 | 0.44 ± 2.42* | 0.64 ± 0.21 | 0.41 ± 0.10* |
| Age (y) | 28.50 ± 1.64 | 26.10 ± 2.42 | 25.80 ± 1.64 | 26.9 ± 3.81 |
| BMI (kg/m²) | 27.05 ± 2.17 | 24.35 ± 2.54 | 20.16 ± 3.09 | 21.55 ± 3.06 |
| MP-H (mm) | 20.67 ± 7.2 | 12.60 ± 6.4* | 13.40 ± 4.39 | 15.90 ± 7.84 |
| RGN-H (mm) | 45.67 ± 6.02 | 42.90 ± 5.28 | 34.80 ± 6.06 | 41.50 ± 8.76 |
| IAS (mm) | 14.67 ± 2.81 | 12.70 ± 5.52 | 13.40 ± 6.69 | 10.60 ± 6.84 |
| MAS (mm) | 17.00 ± 3.80 | 15.60 ± 4.20 | 14.80 ± 6.02 | 13.00 ± 4.50 |
| SAS (mm) | 12.83 ± 1.60 | 12.90 ± 2.64 | 12.20 ± 1.92 | 10.80 ± 3.39 |
| VAL (mm) | 82.50 ± 6.89 | 76.20 ± 5.73 | 65.80 ± 2.59 | 70.40 ± 7.11 |
| TFH (mm) | 135.00 ± 4.98 | 133.80 ± 4.40 | 119.80 ± 7.05 | 123.10 ± 7.13 |
| LFH (mm) | 75.17 ± 4.17 | 73.50 ± 5.60 | 66.40 ± 6.80 | 68.50 ± 6.00 |
| SNA (°) | 83.5 ± 8.46 | 83.20 ± 3.36 | 85.20 ± 4.97 | 83.30 ± 4.64 |
| ANB (°) | 2.33 ± 2.16 | 2.50 ± 1.08 | 5.20 ± 2.59 | 4.30 ± 1.49 |
| MP (°) | 23.00 ± 5.51 | 22.40 ± 3.98 | 28.20 ± 8.08 | 26.00 ± 4.08 |

[a] * Indicates $P < .05$.

**TABLE 3.** Comparisons Between Sex in Responders and Nonresponders (Statistically Significant Variables)[a]

| Variables | Mean ± SD | | | |
|---|---|---|---|---|
| | Responders | | Nonresponders | |
| | Men (n = 6) | Women (n = 5) | Men (n = 10) | Women (n = 10) |
| BMI (kg/m²) | 27.05 ± 2.17 | 20.16 ± 3.09* | 24.35 ± 2.54 | 21.55 ± 3.06* |
| MP-H (mm) | 20.67 ± 7.2 | 13.40 ± 4.39* | 12.60 ± 6.4 | 15.90 ± 7.84 |
| RGN-H (mm) | 45.67 ± 6.02 | 34.80 ± 6.06* | 42.90 ± 5.28 | 41.50 ± 8.76 |
| VAL (mm) | 82.50 ± 6.89 | 65.80 ± 2.59** | 76.20 ± 5.73 | 70.40 ± 7.11* |
| SN-C4 (°) | 102.00 ± 12.22 | 99.20 ± 6.38 | 100.10 ± 6.74 | 107.70 ± 8.45* |
| TFH (mm) | 135.00 ± 4.98 | 119.80 ± 7.05** | 133.80 ± 4.40 | 123.10 ± 7.13* |
| LFH (mm) | 75.17 ± 4.17 | 66.40 ± 6.80** | 73.50 ± 5.60 | 68.50 ± 6.00 |
| ANB (°) | 2.33 ± 2.16 | 5.20 ± 2.59* | 2.50 ± 1.08 | 4.30 ± 1.49* |

[a] * Indicates $P < .05$; ** $P < .01$.

0.1 mV-sec or more in response to the inflation of the balloon in the upright position. The mean value of male responders' GG EMG during balloon inflation in the upright position was 0.63 mV-sec, whereas that of the male nonresponders' was 0.44 mV-sec. The mean GG EMG of female responders was 0.64 mV-sec and that of female nonresponders was 0.41 mV-sec. Based on comparisons of the 18 cephalometric measures evaluated in male subjects, the only statistically significant variable was vertical hyoid position (MP-H) (responders, 20.67 mm vs nonresponders, 12.60 mm). There were no statistically significant cephalometric variables in female subjects between responders and nonresponders. A summary of the cephalometric comparison appears in Table 2.

### Male vs female responders and nonresponders

Analysis comparing responders and nonresponders by sex showed that among the responders, there was a statistically significant difference between the men and women for eight variables: BMI was higher in male responders, vertical hyoid position (MP-H) was more inferior in male responders (males, 20.67 mm vs females, 13.40 mm), horizontal hyoid position (RGN-H) was longer in male responders (males, 45.67 mm vs females, 34.80 mm), and the vertical airway length was longer in the male responders (males, 82.5 mm vs females, 65.80 mm). Sex comparisons for the responders and nonresponders are shown in Table 3.

## DISCUSSION

This study observed that some individuals of both sexes respond with a more reactive GG to partial occlusion of the pharyngeal airway by balloon inflation than others. Interestingly, however, male responders showed a lower hyoid bone position than their nonresponder counterparts (difference of eight mm). In contrast, female responders seemed to have a hyoid that was positioned higher than or at about the same level as that of nonresponders (responders, 13.4 mm vs nonresponders, 15.9 mm). This disparity suggests a heterogeneity of GG muscle function in males vs females. The difference in GG response to partial occlusion of the oropharynx in some males may result from a difference in the position of the hyoid bone. The GG muscle in males with a low hyoid bone might demonstrate a larger compensatory contraction to cope with the partial occlusion of the pharynx because of a biomechanical disadvantage.[16] The finding that OSA subjects show a low hyoid bone and increased GG EMG activity as anatomical and functional characteristics, respectively, implies that potentially responsive subjects might develop OSA symptoms when other predisposing factors are added in this condition.

When cephalometric measurements were compared between men and women among reponders, men were significantly larger than those of women (see Table 3). This is possibly explained by sexual dimorphism in size. Interestingly, however, the two variables representing position of the hyoid bone, MP-H and RGN-H, measured in nonresponders did not reflect such dichotomy. Unlike among male subjects, statistical analysis of measurements from female responders compared with female nonresponders revealed no significant differences (see Table 2). This result could show a sampling bias in BMI in our subjects. However, the smaller female BMI only strengthens the current results. Because obesity generally indicates a narrow upper airway, our lean female subjects would be expected to have a larger pharynx and a higher hyoid bone position than their weight-matched and size-corrected counterparts. However, our results show no sex differences in the measurements of MP-H and inferior airway space (Table 1). Popovic and White[15] found women to have a smaller mean BMI, yet a higher resting GG activity than men. The possibility of compensatory mechanism in GG response to partial occlusion of the pharynx in females might be different from that in males.

The prevalence ratio of men to women with sleep-disordered breathing is reported to range between 2:1 and 3:1.[22] Sleep apnea is uncommon among premenopausal women but increases in prevalence after menopause.[20,22,23] The prevalence of OSA in a large sample that compared women with men while controlling for age, obesity, as well as menopause and hormone replacement therapy has been studied.[24] There was a suggestion that hormone replacement therapy is associated with lower prevalence of sleep apnea, but there was no significant difference identified between the prevalence of sleep apnea in pre- and postmenopausal women undergoing hormone replacement therapy.[23] In women, it has also been proposed that progesterone levels play a role in protecting against the development of sleep apnea.[19,20] Women experience increase in ventilatory drive during the luteal phase of the menstrual cycle when progesterone levels are highest.[21] Oral progesterone has been associated with slight but marked improvement in ventilatory indices during sleep in both men and women who are patients of sleep apnea.[19,20] It has also been suggested that estrogen may increase the sensitivity of ventilatory centers to the stimulant effect of progesterone.[18]

The pharyngeal airway in men is reported to be considerably more collapsible than in women when exposed to greater intraluminal negative pressure.[25] However, this trait seems to begin to express itself as early as eight to 11 weeks of life, when obstructive apneas were significantly more frequent in boys than in girls.[26] Pressure of a few centimeters of water segregates the collapsing pressure of each of these groups. With small samples, the data convincingly demonstrate that the upper airway of men collapses more easily when stressed by a subtle upper-airway resistive load. In age- and weight-matched OSA patients, females show milder OSA symptoms despite a significantly smaller oropharyngeal junction and pharynx than men, which is not surprising.[27]

## CONCLUSIONS

With the limitation of small sample size, this study unexpectedly found that hyoid position and genioglossal response to a partial occlusion of the pharynx are heterogeneous in men and that the heterogeneity may be associated with vertical position of the hyoid bone. The current study could not suggest whether the sex difference in GG response to the partial occlusion of the oropharynx is based on anatomical differences or differences in muscle function itself. On an average, onset of OSA in adults is at middle age.[22] A low hyoid bone position appears to be a universal morphometric characteristic of adult male patients regardless of age[28] and weight.[29] Results of this study suggest that men showing an augmented GG EMG response to the occlusion of the upper airway may have increased risk of developing OSA symptoms if other predisposing factors such as age or weight are present. This suggestion might well require further investigations.

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