Original Article

Respiratory-Related Genioglossus Electromyographic Activity in Response to Head Rotation and Changes in Body Position

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Abstract: The purpose of this study was to assess the effect of changes in body and head positions on respiratory-related activity of the genioglossus muscle in normal subjects in 8 body and head positions: (1) upright body with head straight, (2) upright body with head rotated to the right, (3) upright body with head rotated to the left, (4) supine body with head straight, (5) supine body with head rotated to the right, (6) supine body with head rotated to the left, (7) lateral recumbent body to the right, and (8) lateral recumbent body to the left. Phasic activity of the genioglossus muscle decreased significantly when subjects rotated their heads and moved from the supine to the lateral recumbent position. It is therefore concluded that genioglossus muscle activity is modulated in response to head rotation and changes in body position. (*Angle Orthod* 2000;70:63–69.)

Key Words: Genioglossus muscle, Respiration, Head rotation, Body position, Upper airway

INTRODUCTION

Because the genioglossus (GG) muscle is the main protruder of the tongue, its relaxation and contraction substantially affect the anteroposterior dimensions of the upper airway, especially the oropharynx and hypopharynx.[1] Several studies have shown that changes in head posture,[2–5] mandibular position,[6] breathing route,[7,8]and body position[2,7,9] induce changes in the electromyographic (EMG) activity of the GG muscle in awake humans. In addition, a sleep-related decrease in GG EMG activity[10–12] partially explains sagging of the tongue into the pharyngeal space, which may cause sleep-related breathing disorders such as obstructive sleep apnea (OSA).[13–17] Tonic as well as phasic GG EMG activity, in pace with respiration, plays an essential role in providing adequate upper-airway patency. Indeed, Odeh et al[18] demonstrated that among various upper-airway–dilating muscles, enhanced EMG activity in the GG muscle was most effective in reducing upper-airway resistance and increasing the negative pressure at which upper-airway collapse occurred, independent of head position.

Sleeping position strongly affects upper-airway morphology, which in turn affects respiratory function. In patients who snore and who exhibit hypopnea and OSA, symptoms are more common when lying down than when sitting[19,20] and are also more common when lying supine than when in a laterally recumbent position.[21–23] This phenomenon may be explained by the influence of gravitational pull, which is responsible for posterior displacement of the tongue, because this vector is smaller when the subject is sitting than when lying down, and is also smaller in the lateral recumbent position than in the supine position.[24] Another explanation may be that changes in body position reflexively activate upper-airway–dilating muscles, including the GG muscle. Either of these mechanisms could alleviate upper-airway narrowing and improve sleep-related breathing disorders. Although changes in head position in the sagittal dimension, ie, flexion and extension of the neck, are known to influence upper-airway function,[4,5,15,25] far less is known regarding the effect of changes in head position in the horizontal dimension, ie, head rotation, on upper-airway function.[26] It has been demonstrated that head rotation alters the timing and pattern of infant tidal breathing.[27] Moreover, dysphagia is significantly improved with

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swallowing rehabilitation during head rotation.[28] These findings suggest that head rotation affects upper-airway function.

The purpose of the current study was to assess the effect of changes in body and head positions on respiratory-related GG EMG activity. We hypothesized that head rotation and the lateral recumbent position induce changes in GG EMG activity by changing the relative direction of gravitational pull and/or reflexive modulation.

MATERIALS AND METHODS

Subjects

The present study was carried out on 10 male volunteers with a mean age of 27.1 ± 1.66 years (mean ± standard deviation [SD]) and a mean body mass index of 22.0 ± 2.27 kg/m^2 . Subjects with ongoing respiratory disorders or infections, subjects taking medication known to affect muscle activity, and subjects with severe orofacial skeletal disharmonies were excluded from the study. Informed consent was obtained from each subject before the study.

Simultaneous recordings of GG EMG activity and respiratory movement

EMG signals from the left GG muscle were recorded in a monopolar fashion using a stainless steel fine-wire electrode (diameter, 0.03 mm, MT Giken, Tokyo, Japan) via the perioral approach.[10] The tip of the urethane-insulated wire was bared approximately 2 mm. The wire was inserted using a 27-gauge needle, which was removed immediately after the electrodes were placed. A reference electrode was placed on the left earlobe. EMG activity of the GG muscle was identified by (1) tonic burst activity during tongue protrusion, and (2) rhythmic phasic activity coinciding with inspiration. Respiratory movement of the chest wall was recorded simultaneously by an inductance band (TR-751T, Nihon-Kohden, Tokyo, Japan).

Protocol

Recordings were made in 8 body and head positions: (1) upright body with head straight, (2) upright body with head rotated to the right, (3) upright body with head rotated to the left, (4) supine body with head straight, (5) supine body with head rotated to the right, (6) supine body with head rotated to the left, (7) lateral recumbent body position to the right, and (8) lateral recumbent body position to the left.

In the upright-body position, the subject sat erect in a reclining chair without a headrest and kept the Frankfort horizontal parallel to the floor. In the supine body position, the chair was reclined flat and the subject lay down, using a headrest. The Frankfort horizontal was kept perpendicular to the floor, and the longitudinal head axis coincided with the trunk axis through the use of a pillow. In the lateral recumbent body position, the subject lay on his right or left side and, using a pillow, held his head in line with his trunk. In positions with the head rotated, the subject was instructed to rotate his head as much as possible without overstraining or producing discomfort.

In each position and at least 5 minutes after setting up the electrodes and monitoring respiratory movement and body and head position, GG EMG activity was recorded for 3 minutes. During these recordings, subjects were instructed to breathe 20 times per minute through the nose with the mouth closed and to keep their teeth in contact in the intercuspal position.

After each recording session with the head rotated, subjects were instructed to return their heads to the straight position. Similarly, after each recording session in the lateral recumbent position, subjects returned to a supine position, and we confirmed recovery of GG EMG activity. EMG signals were amplified, band-pass filtered at 50 Hz to 3 kHz, full-wave rectified, and integrated at a time-constant of 0.3 seconds. After the signals were passed through an A/D converter (Maclab/8S, AD Instruments, Castle Hill, Australia), they were stored on a personal computer (Macintosh Performa 5270, Apple Computer, Cupertino, Calif) for data analysis. We also examined the reproducibility and temporal changes in GG EMG activity in 2 subjects, respectively. All EMG signals were recorded and stored in the same manner.

Data analysis

Integrated GG EMG signals were averaged with reference to respiratory movement. Tonic GG EMG activity was defined as the minimum GG EMG activity during expiration. Phasic GG EMG activity was defined as the difference between the maximum EMG activity during inspiration and the minimum EMG activity during expiration. EMG activity was normalized to the maximum value during tongue protrusion in the upright position. In studies of reproducibility and temporal changes in GG EMG activity, EMG activity was standardized to the maximum value during inspiration in the upright position. The paired *t*-test was used to evaluate the dependence of GG EMG activity on laterality, eg, upright body position with the head rotated to the right and left. A 1-way, repeated analysis of variance (ANOVA) was used to investigate significant differences. For the purpose of multiple comparisons, contrasts were used to compare GG EMG activities among different body and head positions in both phasic and tonic activities. Statistical significance was established at $P < .05$.

RESULTS

We observed remarkable changes in GG EMG activity in response to head rotation and changes in body position. Figure 1 shows a typical simultaneous recording of chest wall movement and GG EMG activity when a subject ro-

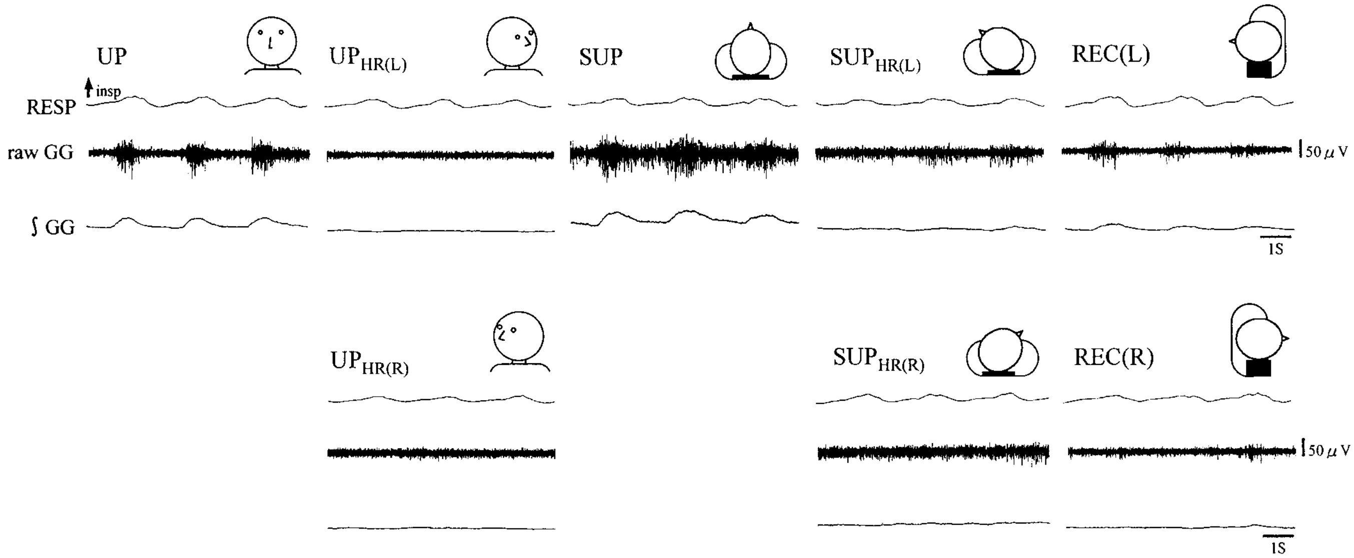

FIGURE 1. Typical simultaneous recordings of chest wall movement (RESP) and raw (raw GG) and integrated (BENTLINE GG) GG EMG activities. Arrow indicates inspiration. Insets schematically show direction of the head in both upright and supine positions and direction of the body in supine position. UP indicates upright position; UP$_{HR(L)}$, upright position with head rotated left; UP$_{HR(R)}$, upright position with head rotated right; SUP, supine position; SUP$_{HR(L)}$, supine position with head rotated left; SUP$_{HR(R)}$, supine position with head rotated right; REC(L), lateral recumbent position to left; and REC(R), lateral recumbent position to right.

tated his head and changed body position. Phasic GG EMG activity was recorded during inspiration in the upright position. When the subject rotated his head to the left, phasic GG EMG activity almost disappeared. A similar change in phasic GG EMG activity was observed when the subject rotated his head to the right. When the subject moved from the upright to the supine position, both phasic and tonic GG EMG activity increased. In the supine position, phasic GG EMG activity decreased when the subject rotated his head to the left or right. When the subject lay on his left side, the GG muscle showed decreased phasic EMG activity relative to activity in the supine position. A similar change in phasic GG EMG activity was observed when the subject lay on his right side.

GG EMG activity was independent of the direction of head rotation and lateral recumbency (Figure 2). Neither phasic nor tonic GG EMG activity was significantly different when the subject rotated his head to either the right or the left in both the upright (Figure 2A, D) and supine (Figure 2B, E) positions. In addition, neither phasic (Figure 2C) nor tonic (Figure 2F) GG EMG activity was significantly different when the subject lay on his right or left side. Table 1 shows mean and standard error values for both phasic and tonic GG EMG activity in different body and head positions. Because GG EMG activity did not significantly depend on the direction of head rotation or recumbency, the mean values for laterality during head rotation in the upright position, head rotation in the supine position, and lateral recumbent position are calculated and used hereafter.

Changes in GG EMG activity in response to head rotation and changes in body position are illustrated in Figure 3. Phasic GG EMG activity decreased significantly when the head was rotated in the upright position (Figure 3A). When the subject moved from the upright to the supine position, phasic GG EMG activity increased significantly.

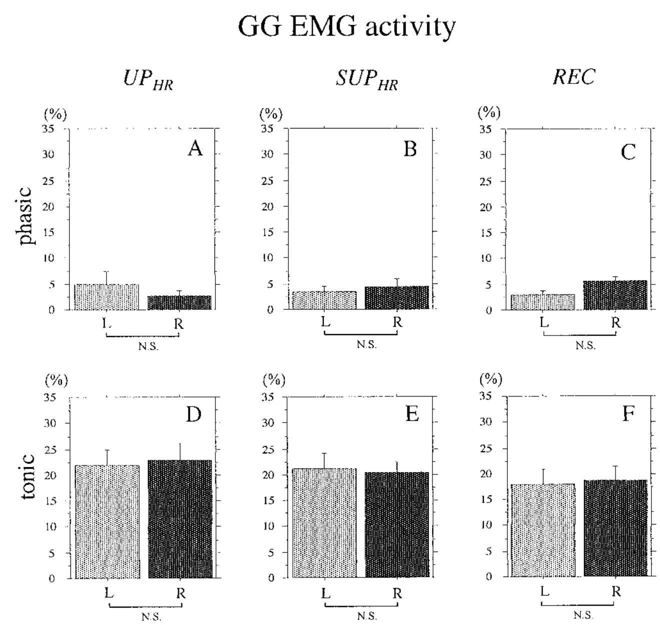

FIGURE 2. Comparisons of phasic (A–C) and tonic (D–F) GG EMG activity during head rotation to left (L) and right (R). GG EMG activity is standardized to the maximum value during tongue protrusion in the upright position. UP$_{HR}$ indicates upright position with head rotated; SUP$_{HR}$, supine position with the head rotated; REC, lateral recumbent position; and NS, not significant. Vertical bars indicate standard errors.

TABLE 1. Phasic and Tonic GG EMG Activity During Head Rotation and in the Lateral Recumbent Positions to the Left and Right*

Activity	Side	
Phasic	Left	Right
UP_{HR}	4.97 (2.53)	2.65 (1.15)
SUP_{HR}	3.40 (1.15)	4.48 (1.46)
REC	3.00 (0.74)	5.59 (0.90)
Tonic	Left	Right
UP_{HR}	21.93 (2.90)	22.92 (3.15)
SUP_{HR}	21.10 (3.05)	20.54 (1.81)
REC	18.07 (2.91)	18.74 (2.65)

* Data are given as mean (SE) percent. GG indicates genioglossus; EMG, electromyogram; UP_{HR}, upright position with head rotated; SUP_{HR}, supine position with head rotated; and REC, lateral recumbent position.

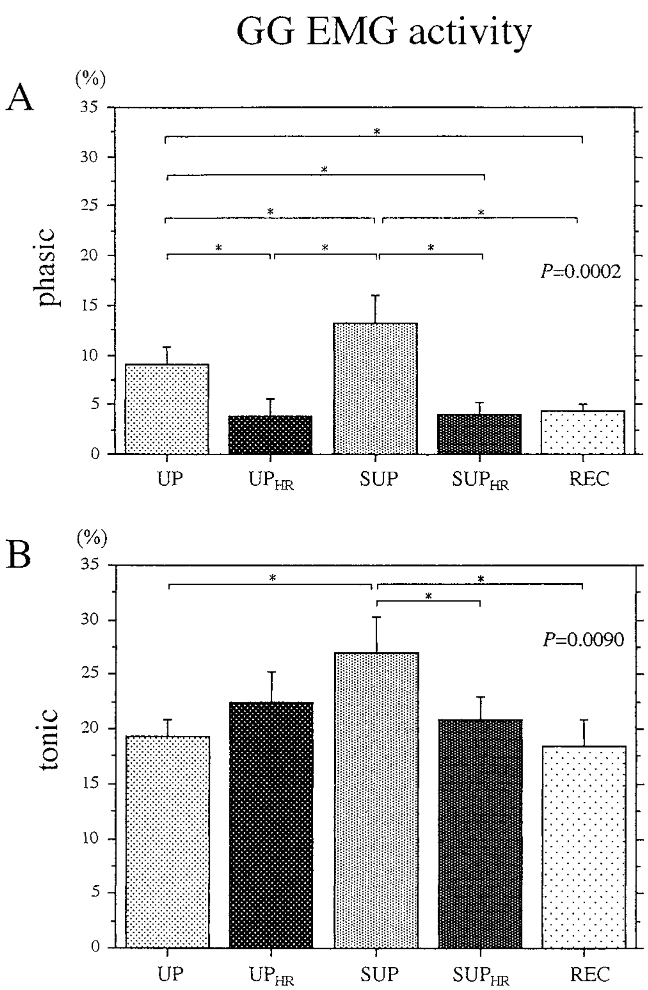

FIGURE 3. Comparisons of phasic (A) and tonic (B) GG EMG activity in different body and head positions. *P* values revealed by ANOVA are shown in each panel. GG EMG activity is standardized to the maximum value during tongue protrusion in the upright position. UP indicates upright position; UP_{HR}, upright position with head rotated; SUP, supine position; SUP_{HR}, supine position with head rotated; and REC, lateral recumbent position. Vertical bars indicate standard errors.

TABLE 2. Phasic and Tonic GG EMG Activity in Different Head and Body Positions*

	Activity	
Position	Phasic	Tonic
UP	9.04 (1.67)	19.32 (1.59)
UP_{HR}	3.81 (1.69)	22.43 (2.83)
SUP	13.30 (2.73)	26.92 (3.43)
SUP_{HR}	3.94 (1.24)	20.82 (2.19)
REC	4.29 (0.74)	18.41 (2.49)

* Data are given as mean (SE) percent. GG indicates genioglossus; EMG, electromyogram; UP, upright position; UP_{HR}, upright position with head rotated; SUP, supine position; SUP_{HR}, supine position with head rotated; and REC, lateral recumbent position.

TABLE 3. *P* values for Multiple Comparison Tests

Activity	Position				
Phasic	UP	UP_{HR}	SUP	SUP_{HR}	REC
UP		.004*	.0173*	.0049*	.0084*
UP_{HR}			.0001*	.9393	.7773
SUP				.0001*	.0001*
SUP_{HR}					.8362
REC					
Tonic					
UP		.1988	.0029*	.5309	.7035
UP_{HR}			.0671	.5032	.0992
SUP				.0147*	.001*
SUP_{HR}					.3162
REC					

UP indicates upright position; UP_{HR}, upright position with head rotated; SUP, supine position; SUP_{HR}, supine position with head rotated; and REC, lateral recumbent position. * $P < .05$.

However, when the subject rotated his head, phasic GG EMG activity decreased significantly in the supine position. Moreover, when the subject moved from the supine to the lateral recumbent position, phasic GG EMG activity decreased significantly. In contrast, tonic GG EMG activity showed less significant variation in response to changes in body and head positions (Figure 3B); tonic GG EMG activity increased significantly when the subject moved from the upright to the supine position. In addition, when the subject rotated his head, tonic GG EMG activity decreased significantly in the supine position. Moreover, when the subject moved from the supine to the recumbent position, tonic GG EMG activity decreased significantly. Table 2 shows means and standard errors in both phasic and tonic GG EMG activity in each body/head position. The *P* values for multiple comparisons are shown in Table 3.

The reproducibility of GG EMG activity in response to head rotation and changes in body position was examined in 2 subjects on different days (Figure 4). With regard to phasic GG EMG activity, values in the upright position with the head straight tended to be greater than those in the upright position with the head rotated for both subjects. In addition, values in the supine position with the head straight tended to be greater than those in the supine position with the head rotated and greater than those in the lateral recumbent position. Moreover, values in the supine position consistently seemed to be greater than values in the upright position. Regarding tonic GG EMG activity, values in the supine position consistently appeared to be greater than those in the upright position. In addition, values in the supine position with the head straight appeared to be greater than those in the supine position with the head rotated and those in the lateral recumbent position.

In the present study, we investigated temporal changes in GG EMG activity in 2 subjects. In these studies, GG EMG activity in each position was recorded for up to 20 minutes (Figure 5). In both subjects, phasic GG EMG activity was always greater in the supine position than in the upright position. In addition, phasic GG EMG activity was almost always less in the supine position with the head rotated and in the lateral recumbent position than in the upright or supine positions with the head straight. Tonic GG EMG activity was always greater in the supine position than in the upright position. In addition, tonic GG EMG activity was always less in the supine position with the head rotated and in the lateral recumbent position than in the supine position with the head straight.

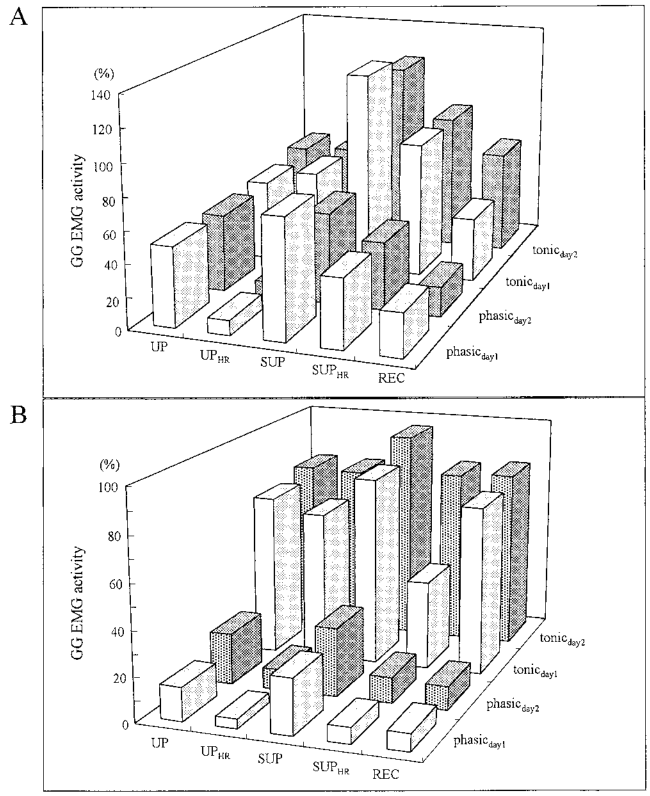

FIGURE 4. Mean of phasic and tonic GG EMG activity values in 2 subjects (A, B) in different body and head positions on different days. GG EMG activity is normalized to the maximum value during inspiration in the upright position. UP indicates upright position; UP_{HR}, upright position with head rotated; SUP, supine position; SUP_{HR}, supine position with head rotated; REC, lateral recumbent position; $phasic_{day1}$, phasic GG EMG activity recorded on first day; $phasic_{day2}$, phasic GG EMG activity recorded on second day; $tonic_{day1}$, tonic GG EMG activity recorded on the first day; and $tonic_{day2}$, tonic GG EMG activity recorded on second day.

DISCUSSION

GG EMG activity and changes in body positions

Many studies have examined changes in GG EMG activity when subjects move from an upright position to a supine position. Sauerland and Mitchell[2] observed activation of the GG muscle with a change from the head-up to the supine-body position. In addition, Pae et al[14] reported that GG EMG activity was approximately 34% greater in the supine position than in the upright position. In the present study, both phasic and tonic GG EMG activity increased significantly in association with a change from the upright to the supine position, which was in accordance with previous studies.[2,14] Takahashi et al[29] suggested that gravity would pull the tongue posteriorly with a change from the upright to the supine position and that augmented GG EMG activity in the supine position could counteract the increased effect of gravity to maintain adequate upper-airway patency. In contrast, Wasicko et al[30] reported that there was less GG EMG activity in the supine position than in the head-up position. They suggested that the increment in GG EMG activity reported by Sauerland and Mitchell[2] was short-term and may have been related to movement of the head per se, which could possibly activate GG EMG activity via vestibular mechanisms. It is known that vestibular afferents are stimulated during dynamic head movements.[31–33] In the present study, because each subject kept his head and jaw in a given position during recording, it is unlikely that vestibular mechanisms were involved in inducing changes in GG EMG activity. Although we examined temporal changes in GG EMG activity in only 2 subjects for up to 20 minutes, the above assumption is supported by the consistent GG EMG activity we observed.

Head rotation and GG EMG activity

We were interested in examining the effect of the direction of head rotation on GG EMG activity, because it is known that head rotation activates the tonic neck reflex pathway and that this reflex affects extreme muscles in a laterally asymmetric manner. These reflexes have been characterized in the orofacial region. Funakoshi and Amano[26] studied the effect of the tonic neck reflex on jaw muscles in the decerebrated rat. They demonstrated that when the head was rotated, the temporal, masseter, and digastric muscles were activated with ipsilateral dominance. In our study, however, there was no laterality in the effects of head rotation on GG EMG activity. This may be because of specific anatomical features of the GG muscle, which originates from the mental spine of the mandible and runs mid-

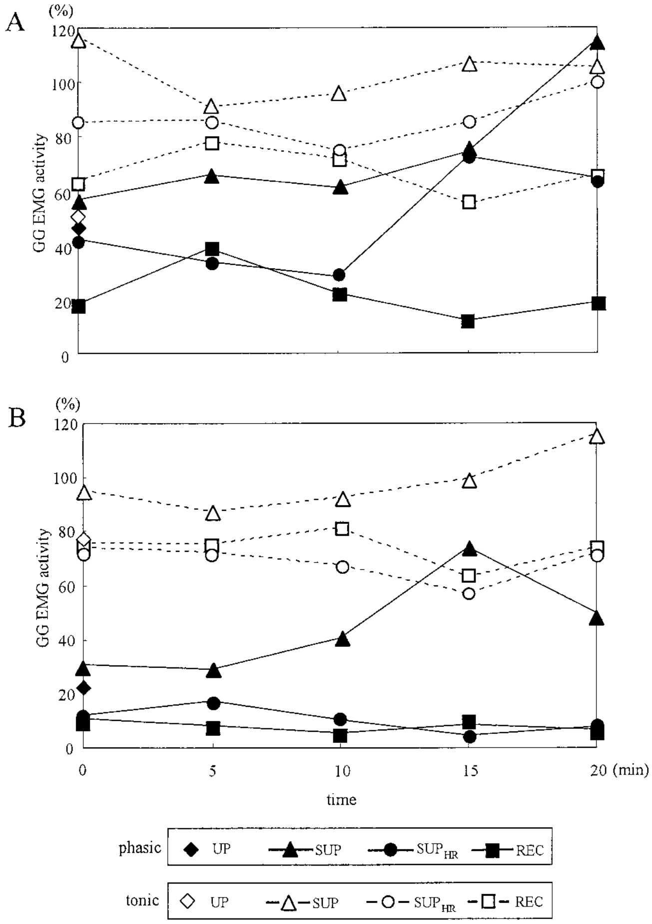

FIGURE 5. Temporal fluctuation of GG EMG activity in 2 subjects (A, B) in different body and head positions. Recordings were repeated for 20 minutes for each position. GG EMG activity is normalized to the maximum value during inspiration in the upright position.UP indicates upright position; UP_{HR}, upright position with head rotated; SUP, supine position; SUP_{HR}, supine position with head rotated; and REC, lateral recumbent position.

sagittally toward the tongue body. Therefore, it may not be necessary for the GG muscles on either side to behave differently when the head is rotated. However, further studies are needed to explain why head rotation causes GG EMG activity to decrease rather than increase.

Phasic GG EMG activity decreased during head rotation in both the upright and supine positions in the present study. Ohmae et al[34] and Karaho et al[35] examined morphological changes in the pharynx during head rotation. They reported that bony structures, such as the mandible, hyoid bone, and thyroid cartilage, rotated with the cervical spine but that less rotation was observed for more caudal structures. They also showed that upper-esophageal resting pressure decreased significantly during head rotation. Their studies suggest that morphological changes in the upper airway are attributable to changes in the position of the hyoid bone and the larynx. The hyoid bone is suspended by supra- and infrahyoid muscles and surrounding soft tissue that could be deformed by head rotation. Because it has been shown that forces acting on the hyoid bone can change upper-airway resistance during respiration,[1,36] it is likely that displacement of the hyoid bone by head rotation can maintain adequate upper-airway patency. If this is the case, the GG muscle would not necessarily be activated during head rotation. Therefore, we speculate that the change in position of the hyoid bone may account for the decreased GG EMG activity during head rotation.

Lateral recumbent position and GG EMG activity

Little is known about changes in upper-airway physiology in the lateral recumbent position. In our study, we observed significant decreases in both phasic and tonic GG EMG activity when subjects moved from the supine to the lateral recumbent position. Using the acoustic reflection technique, Jan et al[4] found that there were no significant differences between upper-airway cross-sectional areas in the supine and lateral recumbent positions in normal awake subjects. A factor that may explain the our discrepant findings is the difference in the relative direction of the gravitational pull on the tongue: there is less gravitational effect in the lateral recumbent position than in the supine position. Pevernagie et al[16] studied the influence of changes in the direction of the gravitational pull on upper-airway structures in patients with OSA. They reported that in both the supine and lateral recumbent positions, subjects with positional OSA, ie, patients in whom the rate of apnea and hypopnea during sleep in the supine position was 2 or more times greater than the rate in the lateral position, had a larger upper-airway cross-sectional area during wakefulness than subjects with nonpositional OSA.[21,22] They also demonstrated that subjects with positional OSA had a greater transverse upper-airway diameter in the lateral recumbent position than did subjects with nonpositional OSA. Accordingly, they assumed that gravity predisposed patients with nonpositional OSA to upper-airway collapse when they slept on their sides and that gravity had a smaller effect on patients with positional OSA. Although we did not examine morphological changes in the upper airway in response to movement from the supine to the lateral recumbent position in the current study, it is possible that the decreased gravitational force on the tongue in the lateral recumbent position diminishes encroachment of the tongue on the upper airway,[37] which in turn requires less GG EMG activity.

CONCLUSIONS

Head rotation induced significant reductions in phasic GG EMG activity in both the upright and supine positions and in tonic GG EMG activity in the supine position. Both phasic and tonic GG EMG activities decreased significantly when subjects moved from the supine to the lateral recumbent position. Although these findings need to be explained in the context of several associated factors contributing to the dimensions of the upper airway, such as gravitational pull, neuromuscular compensations, and the lateral pharyngeal fat pad, the interaction of body and head position and upper-airway–muscle function during wakefulness may have profound implications for sleep-disordered breathing.

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