Heterogeneous activity of the human genioglossus muscle assessed by multiple bipolar fine-wire electrodes

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Eastwood, Peter R., Garry T. Allison, Kelly L. Shepherd, Irene Szollosi, and David R. Hillman. Heterogeneous activity of the human genioglossus muscle assessed by multiple bipolar fine-wire electrodes. J Appl Physiol 94: 1849–1858, 2003. First published January 3, 2003; 10.1152/japplphysiol.01017.2002.—Genioglossus (GG) electrical activity [measured by electromyogram (EMGgg)] is best measured by intramuscular electrodes; however, the homogeneity of EMGgg is undefined. We investigated the relationships between EMGgg and the site from which activity was measured to determine whether and to what extent inhomogeneity in activity occurred. Eight healthy human volunteers underwent ultrasound to determine GG depth and width. Four pairs of electrodes were then inserted percutaneously into the left and right GG muscles, anteriorly and posteriorly. Additional configurations were obtained by connecting electrodes across the midline and along each muscle belly. EMGgg activity was simultaneously recorded from these 10 configurations at rest and during various respiratory maneuvers. Heterogeneous behavior of the GG was evidenced by 1) the variable presence of phasic EMGgg at rest, which was undetectable in two subjects but evident in 65% of configurations in six subjects and present in all configurations in all subjects during voluntary hyperventilation; 2) a greater amplitude of EMGgg response to pharyngeal square-wave negative pressure in anterior than posterior configurations (14.1 ± 7.1 vs. 8.5 ± 5.1% of maximum, P < 0.05); and 3) variable (linear and nonlinear) relationships between EMGgg and lingual force within and between subjects. We hypothesize that regional differences in density and type of muscle fiber are the most likely sources of heterogeneity in these responses.

obstructive sleep apnea; upper airway collapse; dilator; ultrasound

THE GENIOGLOSSUS IS the major dilator muscle of the upper airway. This has made it the primary muscle examined in many studies of the pathophysiology of obstructive sleep apnea, a condition characterized by repetitive collapse and reopening of the upper airway. Its behavior has been described mainly in terms of its electrical activity, which has been shown to be increased during wakefulness in obstructive sleep apnea (12), to decrease with change in sleep state and during anesthesia (14, 17), and to be related to changes in upper airway collapsibility (19).

The current “gold-standard” method of measuring genioglossus electromyogram (EMG) is via fine-wire intramuscular electrodes placed according to the procedures described by Sauerland and Harper (17). In their study, Sauerland and Harper noted increased phasic activity when electrodes were inserted via a peroral approach but not when inserted via a percutaneous approach. They hypothesized that this difference was due to the location of the recording electrodes in the genioglossus. They suggested that the peroral approach positioned the wires closer to the insertion of the genioglossus to the mandible, where the density of muscle fibers is greater, whereas a percutaneous approach placed the wires more caudal, where the muscle density is less, with subsequent loss of ability to detect phasic activity. Thus the present recommendation is to adopt a peroral approach, even though the differences reported between the percutaneous and peroral approach were based on data from only two subjects (17).

However, many subsequent studies using this peroral approach have reported difficulties in detecting phasic genioglossus muscle activity when breathing at rest (4, 9, 22, 23). This has caused investigators to discard data on the basis of no phasic EMG activity. It remains unclear whether this is due to inappropriate positioning of the electrodes in or around the muscle or to inhomogeneous behavior of the muscle itself.

Since the original work of Sauerland and Harper, there have been no studies specifically examining the relationships between the EMG activity of the genioglossus and the site from which activity is measured. The purpose of the present study was to systematically investigate these relationships to determine whether and to what extent inhomogeneity in activity occurred. To do so, we planned to use ultrasound to define submental anatomy and precisely position recording electrodes at multiple sites within the genioglossus muscle. We decided to adopt a percutaneous approach to...
subjects and protocol

subjects and protocol

insert the fine-wire electrodes for this study because it is well tolerated, does not require local anesthesia, and allows easier access than a peroral approach, while avoiding difficulties associated with wires traversing the mouth (6, 7). We believed that these potential advantages justified an investigation of the utility of the technique, which had previously been dismissed by others on the basis of minimal data (17).

methods

subjects and protocol

Eight normal healthy volunteers without any history of pulmonary, neuromuscular or sleep disorders were recruited (Table 1). Informed consent was obtained before subjects participated in the study, which was approved by the Institutional Ethics Committee of Sir Charles Gairdner Hospital.

Studies were performed with subjects supine and the head placed in a neutral position by using a Shea headrest. Ultrasound images of the tongue and floor of the mouth were obtained to determine the depth and width of the genioglossus muscle. On a subsequent day (guided by the measurements obtained via ultrasound), four sets of bipolar fine-wire recording electrodes were inserted percutaneously into the left and right genioglossus muscles by using separate 25-gauge sterile needles as guides. The wires were 0.08 mm in diameter and insulated with nylon, except for the last 0.5 mm, which had been stripped bare. The tip of each wire was bent over the bevel of the needle so that the wire remained in place after the guide needle was withdrawn (3). Intertip distance was —2.0 mm (17). Needles were inserted in a sagittal plane (90°) into the chin at 10 and 20 mm from the inferior margin of the mandible. The site of insertion from the midline as well as the depth of insertion were predetermined from measurements derived from each individual’s ultrasound scans (see Ultrasound above). After removal of the needle, the wires were securely taped into place and attached to copper spring clips soldered to the free ends of the amplifier lead wires. Performance of the fine-wire electrodes was optimized by reversing the current flow to remove any polarizing that may have existed (2).

Each electrode pair was referenced to a common ground (placed on the forehead) to yield a bipolar recording (L1, L2, R1, and R2) (Fig. 1). Single wires from each pair were connected to provide an EMG signal from along each muscle belly (L3 and R3), across the midline (LR1 and LR2), and diagonally across the midline (LR3 and LR4). Raw signals from each electrode pair were amplified, band-pass filtered between 30 and 1,000 Hz (model 7P511J, Grass Instruments, Quincy, MA), and digitally recorded continuously at 2,000 Hz (Powerlab 16s, ADInstruments). These EMGs were rectified and integrated on a moving-time-average basis with a time constant of 100 ms. At the end of each study, gentle traction was applied to remove the wires, and the depth of insertion was noted. This was compared with the target depth, and any differences (indicating electrode displacement) were noted.

Flow and pressure. Subjects breathed via a tight-fitting facemask (with nose occluded) when mouth breathing or via

measurements

ultrasound. Submental soft tissue anatomy was examined by using a high-resolution 8-MHz ultrasound linear probe (Acuson 128 computed sonography system; Acuson, Mountain View, CA). Saggital scans were obtained with the transducer directed vertically under the chin in the midline and coronal scans obtained by turning the transducer 90° from this position (20). During each scan, care was taken to minimize compression of the skin under the chin by the probe, and scanning sessions were recorded on videotape.

At 10 and 20 mm from the inferior margin of the mandible, measurements were obtained of the distance between the probe (skin surface) and 1) inferior margin of the geniohyoid, 2) interface of the geniohyoid and genioglossus, 3) superior margin of the genioglossus, 4) floor of the mouth, and 5) genioglossus width. A built-in electronic calliper was used for these measurements, which were made in duplicate. The average values were recorded.

Genioglossus EMGs. A topical anesthetic (EMLA cream, Astra Pharmaceuticals, North Ryde, Australia) was applied to the underside of the chin for 40–60 min, after which four sets of bipolar stainless steel fine-wire recording electrodes were inserted percutaneously into the left and right genioglossus muscles by using separate 25-gauge sterile needles as guides. The wires were 0.08 mm in diameter and insulated with nylon, except for the last 0.5 mm, which had been stripped bare. The tip of each wire was bent over the bevel of the needle so that the wire remained in place after the guide needle was withdrawn (3). Intertip distance was —2.0 mm (17). Needles were inserted in a sagittal plane (90°) into the chin at 10 and 20 mm from the inferior margin of the mandible. The site of insertion from the midline as well as the depth of insertion were predetermined from measurements derived from each individual’s ultrasound scans (see Ultrasound above). After removal of the needle, the wires were securely taped into place and attached to copper spring clips soldered to the free ends of the amplifier lead wires. Performance of the fine-wire electrodes was optimized by reversing the current flow to remove any polarizing that may have existed (2).

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Flow and pressure. Subjects breathed via a tight-fitting facemask (with nose occluded) when mouth breathing or via

# Table 1. Subject characteristics

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<td>108</td>
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</tbody>
</table>

BMI, body mass index; F, female; M, male.
a nasal mask (with mouth occluded) when nose breathing. Under each condition, a pneumotachograph (Hewlett Packard 47303A, Waltham, MA) was connected to measure airflow, and pressure was measured via a side port in the mask (model 143PC, Micro Switch, Honeywell, Morristown, NJ). Before each study, the pneumotachograph was calibrated over a range of flows by using a 3-l syringe, and the pressure transducer was calibrated against a water manometer.

Negative pressure pulses. Between three and five pulses of negative pressure were applied to the nasal mask at end expiration or early inspiration by briefly exposing the mask to a postsubatmospheric pressure via a regulated vacuum source (model VFC204P, Fuji Electric, Tokyo, Japan). At least 10 breaths were permitted between each pressure pulse. The magnitude of each pulse was \(-11.4 \pm 1.2\) cmH2O and lasted 820 \(\pm 290\) ms. The characteristic of each pulse was such that the time from onset of pressure generation to maximal pressure was \(110 \pm 70\) ms, which was then maintained for 570 \(\pm 140\) ms. Thereafter, the pressure decayed to baseline over 140 \(\pm 100\) ms.

Lingual force. A tongue protrusion force transducer was constructed according to the specifications described by Mortimore et al. (13). Essentially, the transducer consisted of a machined nylon handgrip and mouthpiece. The mouthpiece consisted of a 10-mm-diameter nylon plate, behind which was positioned a load cell. Behind the plate, the mouthpiece consisted of a groove \(\sim 2.0\) mm deep and 2.0 mm wide. Subjects were asked to rest their upper and lower incisor teeth in the groove; thus the mouth was slightly open. During measurements, the movement of the plate on the load cell was \(<1.0\) mm. The force transducer was calibrated before each study with weights of known mass placed on top of the force transducer.

Maximal force was defined as the peak tongue protrusion force able to be generated in three trials in which the peak values were within 5\% of each other. Once this was defined, subjects were instructed to perform repeated efforts at a force equivalent to 20, 40, 60, and 80\% of maximum. Each effort was maintained for \(\sim 5\) s. The order of efforts was randomized, and at least 60 s was permitted between efforts.

Insertion and Position of Fine-Wire Electrodes

Subjects described the process of inserting the needle/wire as being accompanied by a sensation of “pressure under the tongue,” rather than being painful. Prior application of the topical anesthetic abolished skin sensation. There was no discomfort reported with removal of the guide needle or of wires at the end of the study.

On removal, it was noted that several wires were displaced (either during removal of the guide needle or during maneuvers) relative to the original target insertion depth, particularly in two subjects. In subject 3 electrodes R1 and R2 were 9 and 16 mm more superior than the target depth, and in subject 5 electrodes L2, R1, and R2 were 8, 10, and 8 mm more superficial than the target depth. On the basis of each individual’s ultrasound measurements (Table 2), the effect of such displacement would have been to site several of these electrodes in the geniohyoid muscle (electrodes R1 and R2 in subject 3 and electrode R1 in subject 5) and others near the interface of the geniohyoid and genioglossus muscles (electrodes R2 and L2 in subject 5). Although we note the presence or absence of activity from these electrodes at rest and in response to voluntary hyperventilation, negative pressure, and tongue protrusion, we have excluded these data from any analyses of group behavior. All other electrodes in these and other subjects were within 2 \(\pm 3\) mm of the target depth.

Genioglossus EMG Activity During Quiet Breathing and Hyperventilation

Presence of phasic activity during quiet breathing. We were unable to obtain any EMG signal in subject 6 in configuration L1, presumably because the wires were touching and the bipolar configuration had
When sampling muscle activity from configurations in two subjects (subjects 5 and 6). There were no obvious anatomic or other characteristics of these two subjects that separated them from the others. In any given subject, when present, phasic activity was not necessarily seen in all configurations. Data from this configuration in this subject were excluded from all subsequent analyses. Phasic activity was absent in any configuration that had been displaced superficially by >5 mm from the target depth (see Insertion and Position of Fine-Wire Electrodes, subjects 3 and 5, above). Even when excluding these configurations from subsequent analyses, the remaining data showed no obvious relationship between the presence or absence of phasic activity and the final depth of insertion relative to the target depth.

Phasic inspiratory activity was evident during quiet breathing in six subjects but undetectable in any configuration in two subjects (subjects 5 and 6). There were no obvious anatomic or other characteristics of these two subjects that separated them from the others. In any given subject, when present, phasic activity was not necessarily seen in all configurations. When sampling muscle activity from configurations with electrodes placed close together, phasic activity was evident in 79% of the anterior configurations (L1, R1) and 38% of the posterior configurations (L2, R2). When muscles were sampled via electrodes spaced further apart, phasic activity was seen in 75% of configurations along the muscle belly (L3, R3), in 67% of configurations across the midline (LR1, LR2), and in 67% of configurations diagonally across the midline (LR3, LR4).

Magnitude of tonic and phasic activity during quiet breathing. Generally, for any given configuration, if phasic activity was present when breathing via the nose, it was also present when breathing via the mouth. In the six subjects with phasic activity during quiet breathing, the magnitude of phasic and tonic activity during mouth breathing was 7.2 ± 1.7 and 4.0 ± 1.7% of maximum, respectively, and during nose breathing was 8.4 ± 3.8 and 4.5 ± 1.4% of maximum, respectively. The magnitude of phasic activity was similar whether breathing via the nose or mouth, as was the magnitude of tonic activity.

During mouth breathing, there was a trend for anterior sampling sites (L1, R1, LR1) to yield greater tonic (4.7 ± 3.0% of maximum) and phasic (7.5 ± 2.8% of maximum) activity, and for configurations diagonally across the midline (LR3, LR4) to yield lower tonic (2.5 ± 1.1% of maximum) and phasic (5.2 ± 2.6% of maximum) activity, although these differences were not statistically significant. A similar trend was noted during nose breathing, where the anterior sampling sites (L1, R1, LR1) yielded the greatest tonic (5.6 ± 2.9% of maximum) and phasic (9.9 ± 6.5% of maximum) activity, and the configurations diagonally across the midline (LR3, LR4) the lowest tonic (2.6 ± 0.9% of maximum) and phasic (4.7 ± 1.9% of maximum) activity, but again these differences were not statistically significant.

**EMG activity during voluntary hyperventilation.** All configurations in all subjects, even those lacking phasic activity during quiet breathing and those displaced electrodes in subjects 3 and 5, showed phasic inspiratory activity during voluntary hyperventilation (Fig. 3). The magnitude of peak phasic activity increased.

<table>
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<tr>
<th>Subject</th>
<th>GH Inferior Margin, mm</th>
<th>GG/GH Interface, mm</th>
<th>GG Superior Margin, mm</th>
<th>Floor of Mouth, mm</th>
<th>GG Width, mm</th>
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Values represent the distance between the probe (skin surface) and the inferior/superior margins of the genioglossus (GG), geniohyoid (GH) and the floor of the mouth when the ultrasound probe was positioned at 10 and 20 mm from the posterior margin of the mandible. GG width was obtained by scanning in the coronal plane. SD, standard deviation.
with increasing inspiratory flow in all configurations \((P < 0.05)\) during both nose and mouth breathing (Fig. 4). At equivalent levels of inspiratory flow, the magnitude of phasic activity was similar between configurations.

**Genioglossus EMG During Negative Pressure Pulses**

An EMG response to a pulse of negative pressure, applied during late expiration or early inspiration, was observed in all configurations in all subjects (Fig. 5),

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**Fig. 2.** Polygraph example from 1 subject showing raw and moving-time averaged (MTA) electromyograms during quiet resting breathing.

**Fig. 3.** Polygraph example from 1 subject showing raw and MTA EMG during quiet resting breathing and during voluntary progressive hyperventilation.
including those displaced electrodes in subjects 3 and 5. The amplitude of the mean EMG response was $11.0 \pm 3.4\%$ of maximum (range 6.0–16.1%). A significantly greater response was observed in the anterior sampling sites (L1, R1, LR1; 14.1 ± 7.1% of maximum) than in the posterior sites (L2, R2, LR2; 8.5 ± 5.1% of maximum) and from along each muscle belly (L3, R3; 8.6 ± 6.0% of maximum) ($P < 0.01$). From the initial decrease in pressure, the time to the onset of EMG activity was $180 \pm 30$ ms, and the time to peak EMG was $420 \pm 40$ ms.

### Genioglossus EMG Activity During Maximal Maneuvers

Robust activity was seen in all configurations during all maximal maneuvers. The maneuver producing maximal activation of the genioglossus differed between electrode configurations within each subject (Fig. 6). Most commonly, maneuvers producing maximal activity were swallowing and inspiratory efforts via the occluded nose or mouth. Less frequently, max-

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**Fig. 4.** Peak genioglossus EMG amplitude for successive breaths during quiet resting breathing (breaths 1–3) and during progressive voluntary hyperventilation (breaths 4–6) for each of the 10 electrode configurations. Each data point represents the mean data from all subjects ($n = 8$). VI, peak inspiratory flow; SD, standard deviation.

**Fig. 5.** Polygraph example from 1 subject showing raw and MTA EMG responses to application of a square-wave of negative pressure to the nasal mask.
imal activity was observed in some configurations during tongue protrusions, jaw clenches, and sniffs.

Relationship Between Genioglossus EMG and Lingual Force

Subjects were able to generate a maximum lingual force of $1.5 \pm 0.5$ kg. Individual EMG-force relationships for each electrode configuration are shown in Fig. 7. Baseline EMG data (at 0% maximum) were obtained from the average tonic activity recorded during unloaded quiet breathing. The individual relationships between force and EMG were variable, such that some were linear and others nonlinear. Analysis of group mean data showed a trend for the anterior configurations (R1, LR1) to yield greater EMG activity at submaximal levels of force; however, this difference was not statistically significant.

DISCUSSION

The purpose of this study was twofold. First, it was to assess the utility of measuring genioglossus activity with the use of intramuscular electrodes inserted via a percutaneous approach; second, it was to evaluate the homogeneity of its voluntary and reflex activity. Ultrasound was used to define submental soft tissue anatomy (20) to provide measurements for optimally positioning four sets of bipolar fine-wire EMG electrodes into the anterior and posterior genioglossus muscle. Optimal position for insertion of recording electrodes was defined as a point midway between the inferior-superior and midline-lateral margins of the genioglossus. We reasoned that such positioning would serve to minimize recording of activity from muscles adjacent to the genioglossus. Ultrasound evaluation showed that the mean optimal depth for placement of the recording wires via a percutaneous approach was 24 mm, with electrodes positioned 3 mm from the midline.

Cross-connecting wires from each of the four bipolar configurations permitted a total of 10 simultaneous EMG recordings to be obtained on each subject, with each EMG representing activity from a different part of the genioglossus muscle (Fig. 1). Using this technique, we observed heterogeneous behavior of the genioglossus as evidenced by variability in 1) the variable pres-
ence of phasic activity at rest, 2) the magnitude of activity evoked by voluntarily or reflexly increasing drive to it, and 3) the relationship between EMG and lingual force. This heterogeneity was observed both within and between subjects.

At rest, phasic inspiratory activity was unable to be detected at all in two subjects but was evident in 65% of configurations in the remaining six subjects. It was notable, however, that as the magnitude of inspiratory effort was gradually increased during voluntarily hyperventilation, all configurations in all subjects, including those without phasic activity during quiet breathing, showed robust inspiratory phasic activity. Vigorous activity was also seen in all configurations during maximal swallows, tongue protrusions, or maximal inspiratory efforts against an occluded airway. Furthermore, a response to a square-wave negative pressure was observed in all configurations. These observations imply that there are differences in the threshold for detection of genioglossus activity depending on where in the muscle activity is recorded. This may reflect truly heterogeneous activity of the genioglossus muscle. Alternatively, it may reflect an inability of improperly placed recording electrodes to record low levels of activity, which may be partly explained by the positions of electrodes relative to the innervation zone or the alignment of muscle fibers.

We took great care in this study to first measure the depth and width of the genioglossus and then, based on these measurements, position each electrode pair within the muscle itself. On removal of each set of wires, their length was measured, and most were found to be within 2 mm of the target depth. Thus, with the exception of those that had moved position after insertion, we are confident that the electrodes, even those not showing phasic activity, were sited within the genioglossus muscle. It was of interest that phasic activity was absent in any electrode that had withdrawn by >5 mm from the target depth. This implies that it is more difficult to record such activity from electrodes situated near the inferior border of the genioglossus. Our ultrasound data indicate that use of the peroral approach of Sauerland and Harper (17), whereby the electrodes are inserted 22–25 mm, would have positioned the recording electrodes through the inferior border of the genioglossus and into the geniohyoid muscle (and possibly even the mylohyoid) rather than the genioglossus in all of our subjects. This may, in part, explain the difficulty noted by others in recording phasic activity at rest by using a peroral approach (4, 9, 22, 23). Using our ultrasound data, we would recommend that, if the peroral approach were to be adopted, the optimal depth of insertion should be ~12 mm. Regardless of whether a percutaneous or peroral approach is adopted, the site of insertion should be no more than 3 mm from the midline (18) because the mean thickness of the left and right genioglossus muscle, measured from the midline, was 6 ± 1 mm.

A heterogeneous response of the genioglossus was also observed in terms of the amplitude of its EMG response to voluntary increases in drive and to reflex stimuli. Anterior configurations were associated with a significantly greater response to a square-wave pulse of negative pressure. It was notable that, from the onset of negative pressure, the time to the onset and the peak genioglossus EMG response (180 and 420 ms, respectively) were greater than has been reported previously in awake humans (10, 22). It is likely that differences in methodology explain the differences. Specifically, relative to other studies, our method of application of pressure required a longer time for pressure to fall to its minimum level (110 ms) and, once achieved, it was maintained for a longer time (570 ms). The effect of these differences would be to prolong the time for the initial appearance of EMG activity as well as the attainment of peak activity, so that the magnitude of the latter could be influenced by behavioral as well as reflex inputs (10). Although these differences exist, we emphasize that they do not detract from our principal findings that, when such a stimulus is applied to the upper airway, 1) all electrode configurations demonstrated a response (to the same stimulus) and 2) the magnitude of the response differs between configurations.

Although not reaching statistical significance, anterior configurations also tended to have the highest tonic and phasic activity at rest and greater activity for any given level of lingual force developed during voluntary tongue protrusions. Variability was also observed in the relationship between lingual force and genioglossus EMG, which was linear in some configurations and nonlinear in others. Such an observation closely agrees with the recent findings of Onishi et al. (15), who also noted such variability from eight pairs of bipolar fine-wire electrodes inserted into the vastus lateralis muscle during submaximal and maximal isometric knee extensions.

Several possibilities could explain this heterogeneous response of the genioglossus muscle. One is that the anterior electrodes are positioned closer to the insertion of the genioglossus into the mandible, where the muscle fibers are more densely packed and electrical activity is potentially more easily detected (17). The more posterior the wires are sited, the more diffuse the muscle fibers and the more difficult it may be to detect its activity. We suspect that the percutaneous approach adopted by Sauerland and Harper (17) resulted in their recording electrodes being sited even more posteriorly than our posterior electrodes, in an area where the muscle fibers are distributed even more diffusely and interspersed with fat (20).

Heterogeneity could also occur because of differences in the orientation of the recording electrodes relative to the active muscle fibers (5) and the distance between the electrodes (1), both of which influence the size of the sampling area as well as the amplitude of the EMG (11). Because different motor unit recruitment levels influence the magnitude of the recorded EMG, it is possible that a configuration with a small sampling area (i.e., L1, L2, R1, R2) may be particularly affected by local fiber-type distributions. For example, if an electrode was predominantly near type II muscle fi-
bers, then it is possible that phasic activity could be dampened at low levels of tension but evident at higher levels because it is at this time that these fibers are recruited. It has only been very recently that investigation of the spatial distribution of fiber types in the human genioglossus has been undertaken. In their morphologic and histochemical study of four cadaveric and one autopsy specimen, Saigusa et al. (16) reported that the anterior genioglossus had a higher proportion of type II fibers (69%) than that of the posterior genioglossus (type II 50%). This would indicate a tendency for greater phasic activity during quiet breathing in the posterior genioglossus, rather than in the anterior genioglossus, as was observed in the present study. Although it is possible that the spatial distribution of fiber types in Saigusa’s study (16) is not representative of the subjects in the present study, these differences suggest that our findings cannot be explained by muscle histology alone.

Further examination of the muscle morphometry of the genioglossus suggests that there are also two types of motor units with specific respiratory-related activity. Recently, Tsuchioka et al. (21) showed that there are at least two types of motor units with respiratory-related activity in the human genioglossus: inspiratory motor units that show phasic firing during inspiration and inspiratory/expiratory motor units that show tonic activity with greater firing frequency during inspiration. The two types of respiratory-related motor units show significantly different discharge patterns and are modulated differently in association with head tilt, consistent with the genioglossus muscle being morphologically and functionally differentiated. Notable in their study was that in the 30° head-down position, the inspiratory motor units became silent, even during inspiration, whereas the inspiratory/expiratory motor units maintained the same rate of firing activity during inspiration and expiration, regardless of head position (21). Such an observation has implications for the present study, because it suggests that the presence or absence of phasic inspiratory activity at rest is variable, depending on a number of factors including head position. It would seem plausible, therefore, that the complete absence of phasic activity in any configuration in two subjects at rest reflects a truly phasically silent genioglossus. Why this might apply to some but not all subjects is unclear. It is possible that subjects with a phasically silent genioglossus had airways less predisposed to collapse, although there were no obvious anatomic or other characteristics of these two subjects that separated them from the rest. When the genioglossus is inactive, it is likely that other muscles are assuming its role in the maintenance of airway patency. Such phasic inactivity is consistent with the notion that, at rest, its role may be more closely related to stabilizing airway caliber through tonic activity than restoring patency that has been potentially compromised by the development of transmural collapsing pressures during inspiration (8).

It is also reasonable to attribute the absence of phasic activity in some parts of the genioglossus to true physiological variability. It is likely that the neural input to the muscle is quite different in different areas; therefore, it yields different phasic/tonic activation and responses to respiratory stimuli. As discussed above, the genioglossus muscle is likely to be highly heterogeneous, and it would therefore be quite surprising if the neural output to all portions of the muscle were the same. An implication of these findings is that it is difficult to compare EMG data within or between subjects when the activity was obtained from different parts of the muscle, particularly at low levels of inspiratory drive.

In summary, the data from this study show that phasic genioglossus activity can be detected at rest by using a percutaneous approach. Such an approach is well tolerated, does not require local anesthesia, and allows easier access than a peroral approach, while avoiding difficulties associated with wires traversing the mouth. However, even when positioned within the genioglossus muscle, phasic activity may or may not be evident, and even when present its magnitude is variable. We hypothesize that regional differences in the type of muscle fiber are the most likely sources of inhomogeneity in these responses.

Finally, this study provides a guide to practice in measurement of genioglossus EMG using intramuscular fine-wire electrodes. To detect phasic activity at low levels of inspiratory drive, the optimal electrode positions appear to be in the anterior portion of the genioglossus muscle, sampling over a larger area of muscle. To assess whether the electrodes are in the genioglossus, we suggest monitoring for the presence of a phasic response to brief voluntary hyperventilation. If absent, a second insertion should be considered, the electrodes of which may be connected to the original insertion to sample over a larger area of muscle. Displacement of electrodes during a study is difficult to recognize and can only be defined post hoc. The use of multiple pairs of electrodes protects against this problem.

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