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The Human Tongue during Sleep: Electromyographic Activity of the Genioglossus Muscle

E. K. SAUERLAND AND R. M. HARPER

Department of Anatomy, University of Texas Medical Branch, Galveston, Texas 77550; Veterans Administration Hospital, Sepulveda, California and Department of Anatomy, School of Medicine, University of California, Los Angeles, California 90024

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The bilateral genioglossi muscles of the tongue, by virtue of their protrusive action, play an important role in the mechanics of maintaining an open air passage in the oropharyngeal region. Electromyographic studies of the genioglossus muscle during sleep were conducted in six healthy human volunteers. The principal results are the following: In quiet waking and in quiet sleep (stages I–IV), the genioglossal EMG is characterized by continuous discharges with substantially augmented activity during inspiration. When the subject enters REM sleep, the tonic genioglossal activity almost ceases except for small bursts during the inspiratory phase of respiration. During REM sleep, genioglossal motor units may become inactive for periods of up to 90 sec. However, these silent periods are regularly interrupted by three to six vigorous inspiratory genioglossal bursts. Genioglossal EMG with substantially augmented discharges during inspiration are best recorded from indwelling electrodes placed close to the origin of the muscle. During snoring, the genioglossal activity related to certain phases of the respiratory cycle is vastly increased. The results are discussed in context with problems encountered in hypersomniac patients with the sleep apnea syndrome.

INTRODUCTION

Electromyography (EMG) is an excellent method of exploring and evaluating the human tongue during such vital processes as deglutition and respiration. Of all tongue muscles, the bilateral genioglossus lends itself to a relatively simple electromyographic approach. A number of investigators have studied genioglossal discharge patterns in alert human subjects during various tongue movements, phonation, and deglutition (3, 4, 8).

The genioglossi are the only muscles which protrude the tongue. Bilateral loss of their action (e.g., during general anesthesia or as a consequence of neurological lesions) leads to a relapse of the tongue with the attendant risk of suffocation, particularly in the supine position. Therefore, the genioglossi have been labeled as "safety muscles" (1). These muscles play an important role in the mechanics of maintaining an open air passage in the oropharynx. Sauerland and Mitchell (12, 13) demonstrated in awake human subjects that the genioglossi are activated during respiration, particularly during the inspiratory phase. Their electromyographic studies also showed that the tonic activity of the genioglossi is markedly increased in the supine position. This activity reflects the efforts of the genioglossi to counteract the relapse of the tongue due to its own gravity.

Attention has been focused on hypersomniac patients with the sleep apnea syndrome (5). Although abnormal diaphragmatic mechanisms may be operative in some cases of sleep apnea, airway obstruction has also been implicated (6). Such obstruction of the airway during sleep may lead to severe cardiorespiratory changes and even to death (5, 6). It has also been suggested (14) that airway occlusion caused by relaxation of the tongue against the palate may be a causative factor in the "sudden infant death syndrome."

Remmers, deGroot, and Sauerland (11) have studied the role of the genioglossus muscle in hypersomniac patients with upper airway obstruction during sleep. Such obstruction was associated with genioglossal atonia, whereas substantial bursts of genioglossal EMG activity occurred during unobstructed inspiration. These findings suggest that loss of genioglossal activity during certain sleep phases contributes to inspiratory upper airway obstruction in hypersomniac patients.

The purpose of the present study is to describe genioglossal EMG activity in healthy human subjects during sleep. These data provide a normal physiologic baseline for comparison with dysfunctions, such as the sleep apnea syndrome.

METHODS

Six healthy volunteers, ranging in age from 13 to 42 years, were used in this study. Their major physical characteristics are outlined in Table 1.

Electromyographic Recording Electrodes. Bipolar recording electrodes, similar to those described by Basmajian and Stecko (2), were used. The electrode assembly is depicted in Fig. 1A. Two nylon-coated copper wires (Belden; No. 40 Nylclad) were inserted into a disposable hypodermic needle (23 gauge; 25 and 38 mm length). The insulation at the ends of the fine wires was removed chemically with concentrated sulfuric acid, and the wires were trimmed so that only 0.5 mm of the uninsulated portion remained. With fine forceps the wires were bent sharply, and the wire

TABLE 1

Major Physical Characteristics of Subjects

Subject	Sex	Age (years)	Weight (kg)	Height (m)	Needle insertion
A	♂	12	34	1.46	peroral
B	♂	13	45	1.64	percutaneous
C	♂	17	73	1.85	peroral
D	♀	30	49	1.62	peroral
E	♂	34	102	1.78	peroral
F	♂	42	74	1.80	percutaneous

ends were kept approximately 2 mm apart to avoid a short circuit of the bipolar electrode (insert, Fig. 1A). The assemblies were autoclaved in sterilization envelopes.

Recording Electromyographic Activity from the Genioglossus. Peroral Approach. The technique of peroral needle insertion into the human

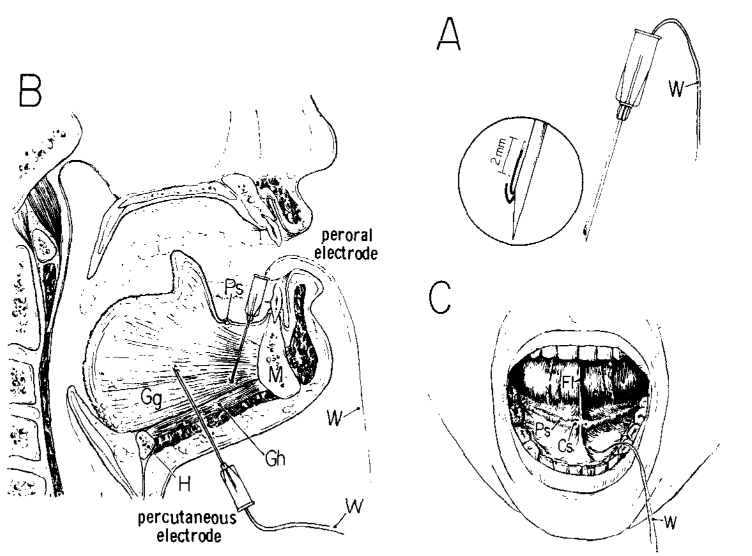

FIG. 1. A. Bipolar recording electrode with disposable hypodermic needle. B. Parasagittal section through portion of head approximately 3 mm from midline. The tongue is actively reflected. Peroral and percutaneous needle insertion into the substance of the genioglossus muscle. C. Recording wires from left genioglossus muscle emerging from floor of mouth after withdrawal of needle. The inferior surface of the tongue is reflected. Abbreviations: Cs, caruncula sublingualis; Fl, frenulum linguae; Gg, genioglossus muscle; Gh, geniohyoid muscle; H, hyoid bone; M, mandible; Ps, plica sublingualis with underlying submandibular duct; W, insulated wire of bipolar recording electrode. [Modified from Sauerland and Mitchell (12).]

genioglossus muscle close to its origin from the inner surface of the mandible has been described earlier (12, 13). Following a thorough mouthwash, the mucous membrane overlying the prospective puncture site was anesthetized with 4% Xylocaine topical solution. The needle assembly, tilted at an angle of about 20°, was inserted at a point 3 mm lateral from the midline and midway between the first mandibular incisor tooth and the sublingual fold. During this procedure, the subject was asked to open the mouth maximally and to reflect the tongue (Fig. 1B). The needle was inserted to a depth of 22 to 25 mm. After withdrawal of the needle, the recording wires remained at their location within the genioglossus muscle due to their barbed wire configuration (Fig. 1C). The peripheral leads of the wires were securely taped to the skin of the chin and face. The electrode position was verified by functional tests of the genioglossus muscle during voluntary activation (13). At the end of the recording session, a gentle pull straightened the barbs of the wires, and the electrodes were removed painlessly (2).

Percutaneous Approach. The method of percutaneous needle insertion into the human genioglossus muscle was described by other investigators (4, 8). As outlined by Hrycyshyn and Basmajian (8), the needle assembly was inserted midway between the symphysis menti and the hyoid bone to a depth of approximately 25 mm (Fig. 1B; percutaneous electrode). Subsequently, the needle was withdrawn leaving the electrode tips embedded in the substance of the genioglossus muscle. The peripheral parts of the recording wires were securely fastened to the chin with surgical adhesive tape. The position of the embedded electrode was verified by functional tests during voluntary activation of the genioglossus muscle.

Monitoring of Other Physiologic Data During Sleep. Silver-plated cup electrodes for monitoring central EEG were applied to exposed and thoroughly cleaned areas of the scalp with Grass EC 2 electrode cream at positions C_3-T_3 according to the international 10-20 system. The subject was grounded through a clip electrode attached to the left ear lobe. Two additional cup electrodes were attached to the skin overlying the mental protuberance and the inferior border of the mandible just anterior to the masseter in order to monitor the "EMG of the chin." Cup electrodes were also applied 2 cm lateral to both eyes to provide indications of eye movements. Respiration was monitored with a bellows belt strapped to the chest (subject D) or to the anterior abdominal wall just below the rib cage (all other subjects). The bellows belt was connected to a Statham PM 5 TC pressure transducer which, in turn, was linked to a transducer bridge circuit. The EKG (lead II) was monitored via cardiac disc electrodes attached to the right forearm and the left leg. The bioelectric and respiratory signals were displayed on paper by a polygraph (Grass Model 6 and

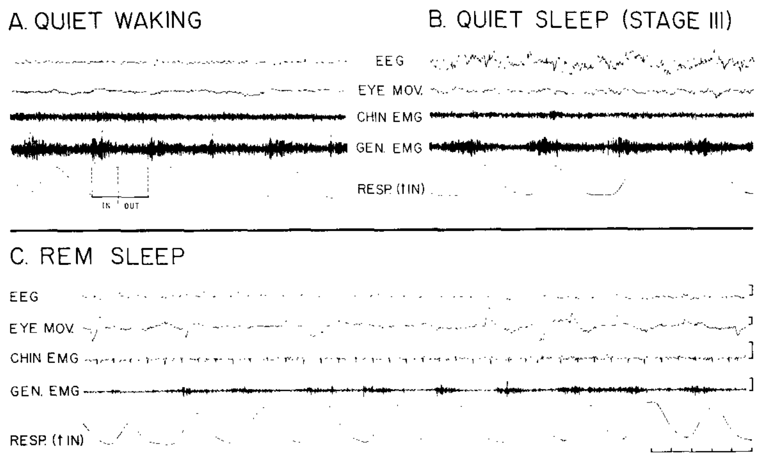

FIG. 2. EEG, eye movements, chin EMG, genioglossal EMG (GEN.), and respiration (RESP.) during waking and sleep states (obese subject E). Note continuous discharges with augmented inspiratory activity of the genioglossus muscle during quiet waking (A) and quiet sleep (B). In contrast, during REM sleep (C) the genioglossal activity almost ceases, except for small bursts during the inspiratory phase. Calibrations: time, 1 sec intervals; amplitudes, 50 μV.

Model 8-16) and concomitantly recorded on a Vetter Model A 8-track FM tape recorder with flutter compensation engaged. An IRIGE time code was simultaneously displayed on paper and recorded on tape for temporal correlation of the two records. The subjects slept in a sound-attenuated, dimly lit, and electrically shielded room. The recordings were taken from the subject's normal bedtime to approximately 7 AM.

The paper records were scored into sleep stages using the criteria of Rechtschaffen and Kales (10). Analysis of respiratory rate and integrated activity was performed on a PDP-12 computer using a sleep analysis package described elsewhere (7).

RESULTS

Peroral EMG During Waking and Various Sleep Phases. Our data consistently show little if any difference in genioglossal muscle activity during wakefulness, particularly quiet waking, and during quiet sleep (stages I through IV). Figure 2A, B illustrates the uniformly observed continuous genioglossal discharges with characteristically augmented activity during the inspiratory phase. This activity pattern was also observed when recording from a small number of motor units or from single motor units (Fig. 3A). A sudden and dramatic change in genioglossal EMG occurred when healthy subjects entered REM sleep. Typically, the genioglossal activity almost ceased except for small bursts during the inspiratory phase (Fig. 2C). The remarkable reduction of motor unit activity during the transition from quiet sleep to REM sleep is demonstrated in Fig. 3B. Characteristically, the tonic discharges with expiration disappeared, and the bursts coinciding with the inspiratory phase became less pronounced. Sometimes, single units became completely inactive for the duration of several respiratory cycles (Fig. 3C). Quiescence lasted 15 to 90 sec. However, these silent periods were always interrupted by three to six vigorous inspiratory bursts (Fig. 3D). When the individual phased from REM into another sleep stage, or when the subject awakened, an immediate increase in tonic as well as in inspiratory phasic discharges became apparent.

Comparison Between Peroral and Percutaneous Recordings of Genioglossal EMG During Sleep. In two subjects the bipolar recording electrode was inserted percutaneously into the genioglossus muscle, whereas in the remaining subjects the peroral approach was used (Table 1). Our records (and additional recent observations in other subjects) show that the peroral approach with electrode deposition close to the origin of the genioglossus muscle yields a particularly vigorous EMG with pronounced augmentation of genioglossal discharges during inspiration in quiet sleep (Fig. 4A). In contrast, the percutaneously inserted electrode, which is

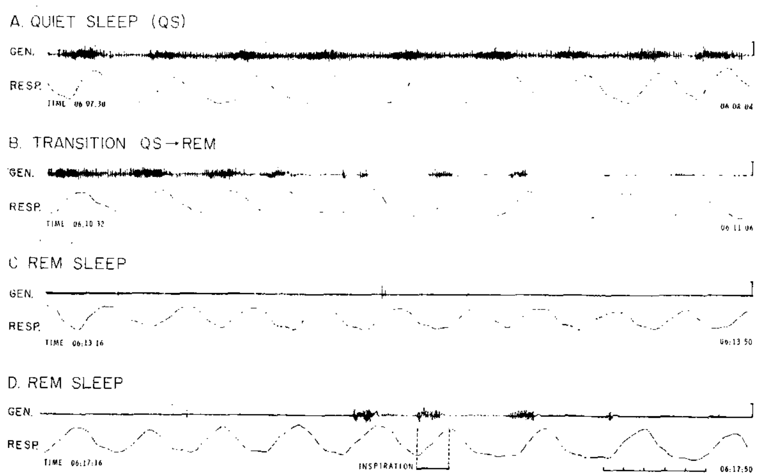

FIG. 3. Activity of a small number of motor units in the right genioglossus muscle during various sleep phases (subject D). Note the increased frequency of discharges during inspiration in quiet sleep (A). During transition from quiet sleep to REM sleep (B), the tonic discharges with expiration disappear and the inspiratory bursts become less pronounced. In REM sleep, motor units may be totally silent for a number of respiratory cycles (C). However, this silence is regularly interrupted by a few inspiratory bursts (D). Calibrations: time, 1 sec intervals; amplitudes, 50 μV.

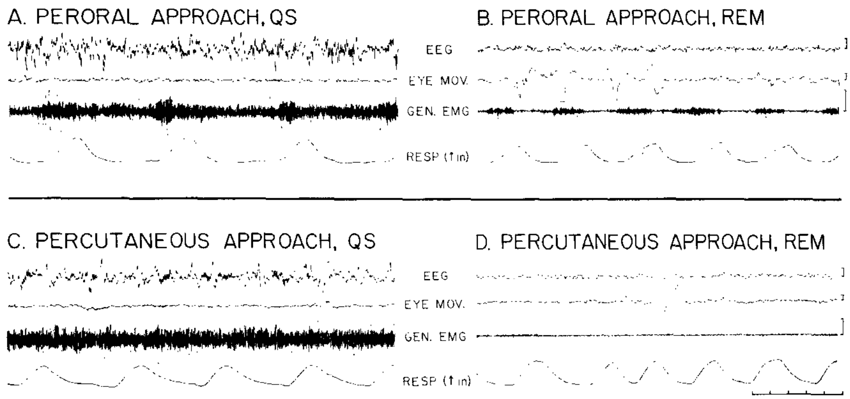

FIG. 4. Electromyographic recordings from the genioglossus muscle obtained with the peroral (A, B) and percutaneous methods (C, D). A. During quiet sleep, the peroral electrode records continuous tonic activity with substantial inspiratory bursts. B. In REM sleep, the genioglossal activity ceases except for small bursts during the inspiratory phase. C. During quiet sleep, the percutaneous electrode registers continuous tonic activity with barely discernible inspiratory bursts. D. Percutaneous recordings during REM sleep are characterized by a virtually silent genioglossal EMG. Calibration: time, 1 sec intervals; amplitudes, 50 μV.

located much more posteriorly in the genioglossal muscle, usually registers only continuous tonic activity with barely discernible inspiratory bursts (Fig. 4C). This difference becomes even more apparent during REM sleep. Whereas the peroral electrode records the characteristic small bursts during inspiration (Fig. 4B), the percutaneously (more posteriorly) inserted electrode registers little if any activity (Fig. 4D).

Genioglossal Activity Pattern During Snoring. Although genioglossal discharges during snoring were obtained only from one individual (obese subject E), the results are communicated here because of the strikingly consistent findings throughout a snoring time in excess of 2 hr. Figure 5 demonstrates that "light snoring" is associated with an increase in genioglossal bursts during the inspiratory phase. During "loud snoring" and "very loud snoring" substantially increased genioglossal activity extends into the expiratory phase. In addition, tongue movement artifacts of very consistent configuration occur. Such activity patterns were observed with the head in the supine as well as in the lateral position. It was noted that the subject snored only during quiet sleep. No snoring episodes were observed in REM sleep.

DISCUSSION

Peroral EMG During Waking and Various Sleep Phases. Our data show that the human genioglossus muscle of the tongue is tonically active

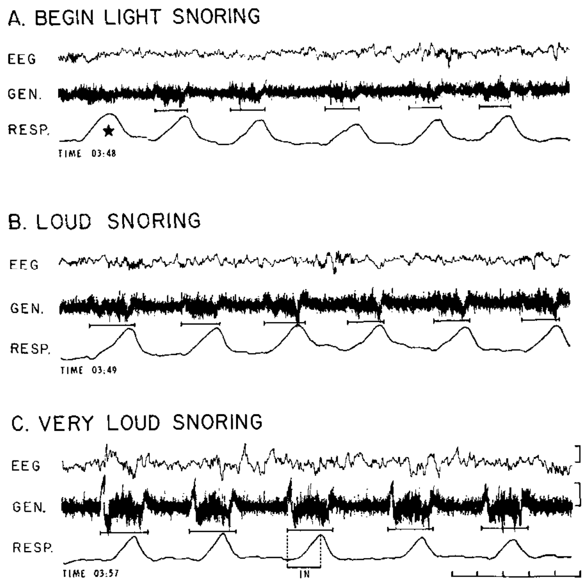

FIG. 5. EEG, respiration (RESP.), and EMG of the left genioglossus muscle (GEN.) during snoring in obese subject E. Periods of audible snoring, marked by horizontal bars, commence at the beginning of the inspiratory phase. The first respiratory cycle (*) is not associated with snoring. A. During light snoring, the inspiratory bursts are substantially increased. B. Loud snoring is associated with genioglossal activity extending into the expiratory phase and showing movement artifacts of the tongue. C. Very loud snoring is characterized by an even more pronounced activity pattern than is described in B. Calibrations: time, 1 sec intervals; amplitudes, 50 μV.

during waking and quiet sleep. During transition from quiet sleep to REM sleep, this tonic activity is reduced, and it may cease later in REM sleep. This change in activity pattern is by no means unique for the genioglossus; other muscles, for example the masticatory and deep neck muscles, behave in a similar manner. Unlike many other muscles, however, the genioglossus displays also a phasic activity which is clearly coupled with respiration. The characteristic tonic and phasic activity patterns of the genioglossus in awake human subjects have been described earlier. Sauerland and Mitchell (12, 13) demonstrated that the human genioglossi are concomitantly activated with the entire inspiratory musculature of the body. The genioglossal EMG is substantially augmented during respiration, particularly during the inspiratory phase. This finding is not surprising if one takes into consideration the efforts of the genioglossus to overcome the air-obstructive relapse of the tongue, particularly in the supine position. Thus, by virtue of their protrusive action, the genioglossi muscles play an important role in the mechanics of maintaining an open air passage in the oropharyngeal region. Other tongue muscles do not participate in this important mechanism (13).

Our data show that in REM sleep the genioglossal activity almost ceases, except for small EMG bursts during the inspiratory phase. Single units or small groups of motor units may be silent for the duration of several respiratory cycles. However, these silent periods are regularly interrupted by intermittent inspiratory genioglossal discharges. As stated above, this pattern of activity can be interpreted as an effort of the genioglossus to maintain sufficient tone during inspiration and to avoid a relapse of the tongue with the attendant risk of occluding the oropharyngeal airway. Our findings indicate that an overall reduction of phasic genioglossal activity normally occurs in REM sleep. However, in healthy human subjects a sufficient amount of EMG activity during inspiration remains, apparently to ensure passage of sufficient air through the oropharynx.

Comparison Between Peroral and Percutaneous Recordings of Genioglossal EMG. The peroral approach with electrode deposition close to the origin of the genioglossus muscle yields a particularly vigorous EMG with pronounced inspiratory genioglossal bursts. In contrast, electrodes which are located much more posteriorly in the muscle (percutaneous approach), register only continuous tonic activity with barely discernible phasic components. The difference in recorded activity becomes particularly apparent during REM sleep—the more posteriorly inserted electrode yields little if any phasic activity. Our observations explain why other investigators who inserted genioglossal electrodes approximately midway between symphysis menti and hyoid bone (3, 4), did not notice the phasic respiratory activity of the genioglossus. At this time, we can only speculate as to why the inspiratory bursts are so well recorded close to the origin of the muscle from the inner surface of the mandible. The most logical explanation would take into account the fan-shaped structure of the genioglossus muscle. Near the origin, the muscle fibers are more densely packed than in the peripheral portions of the muscle. Further studies are indicated to provide a better understanding of this phenomenon.

Genioglossal Activity During Snoring. As the intensity of snoring increases, the genioglossal discharges become more and more vigorous. Initially, during "light snoring," there is an increase in genioglossal bursts during the inspiratory phase. Finally, during "very loud snoring," very substantial genioglossal EMG discharges are present in addition to characteristic tongue movement artifacts which generally extend into the expiratory phase. Our findings agree with those of Lugaresi et al. (9) who examined the nocturnal breathing patterns of heavy snorers. These investigators demonstrated that snoring is primarily an inspiratory noise. It is generally accepted (9) that "snoring is an acoustic phenomenon produced by vibration of the soft palate and the faucial pillars." In view of our present findings it is likely that, in addition, the tongue participates actively in the snoring process.

Clinical Implications. Airway obstruction, associated with apnea or snoring, is of considerable clinical interest. Lugaresi *et al.* (9) stated that snoring is rarely encountered during REM sleep. Our obese subject E snored heavily in quiet sleep, but breathed quietly in REM sleep. According to Guilleminault (personal communication), patients who snore in REM sleep are more likely to be afflicted by cardiorespiratory difficulties resulting from apnea than those who breathe quietly in REM sleep. Lugaresi et al. (9) also reported obstructive apneas in heavy snorers during REM sleep. Further investigations of genioglossal activity in patients whose snoring periods extend into REM sleep are necessary to enhance our understanding of upper airway obstruction in patients with the sleep apnea syndrome.

The loss of tonic genioglossal EMG activity during REM sleep may point to the cause of airway obstruction in patients with the sleep apnea syndrome. Conditions that contribute to upper airway obstruction in patients with this syndrome may include enlarged tonsils, hypertrophied adenoids, and thyroid enlargement. Guilleminault and Dement (6) favor the hypothesis of "an abnormal collapse of the pharyngeal wall," a condition perhaps involving a failure of complex regulatory processes in the central nervous system. Remmers, deGroot, and Sauerland (11) recently studied the role of the genioglossus in hypersomniac patients with upper airway obstruction during sleep. The obstruction was associated with genioglossal atonia, whereas substantial bursts of genioglossal EMG activity occurred during unobstructed inspiration. These findings (11) suggest that loss of genioglossal activity may contribute to upper airway obstruction in certain hypersomniac patients.

Our findings indicate that in some healthy subjects complete loss of genioglossal EMG may occur for the duration of several respiratory cycles in REM sleep. However, these silent periods are regularly interrupted by a few bursts of activity during inspiration. It is possible that these sporadic bursts involve selected groups of motor units which are switched on or off at different times. Thus, the genioglossal musculature as a whole may maintain a certain minimal degree of activity. It is also possible that the sporadic activity bursts thrust the relaxed tongue forward and thereby reposition it temporarily. In other normal subjects, only the tonic activity disappears during REM sleep whereas the inspiratory genioglossal bursts remain. In both types of healthy subjects, the tongue is apparently prevented from relapsing completely against the posterior pharyngeal wall.

Thus, under normal circumstances, a sufficient degree of airflow through the oropharynx is possible during REM sleep. This may not be the case in patients afflicted with the sleep apnea syndrome. Further studies are necessary to ascertain whether the airway obstruction during sleep is due to a dysfunction of central nervous control or due to peripheral causes (e.g. excessive fatty infiltration into the base of the tongue in obese patients).

REFERENCES

1. Basmajian, J. V. 1975. P. 570. *In* "Grant's Method of Anatomy." The Williams and Wilkins Company, Baltimore.
2. Basmajian, J. V., and G. Stecko. 1962. A new bipolar electrode for electromyography. *J. Appl. Physiol.* **17**: 849.
3. Bole, C. T. 1965. Electromyographic kinesiology of the genioglossus muscles in man. M.S. Thesis, Ohio State University, Columbus, Ohio.
4. Cunningham, D. P., and J. V. Basmajian. 1969. Electromyography of genioglossus and geniohyoid muscles during deglutition. *Anat. Rec.* **165**: 401–410.
5. Guilleminault, C., F. Eldridge, and W. Dement. 1973. Sleep apnea: A unique syndrome with important cardio-respiratory changes, p. 150. *In* "Sleep Research," Vol. 2, M. H. Chase, W. C. Stern, and P. L. Walter [Eds.]. UCLA Brain Information Service.
6. Guilleminault, C., and W. Dement. 1974. Pathologies of excessive sleep, pp. 345–390. *In* "Advances in Sleep Research," Vol. 1. E. D. Weitzman [Ed.]. Spectrum Publications, Inc., New York.
7. Harper, R. M., J. Mason, R. Pacheco, and A. Perga. 1975. A computer system for the analysis of physiological data during sleep, in press.
8. Hrycyshyn, A. W., and J. V. Basmajian. 1972. Electromyography of the oral stage of swallowing in man. *Amer. J. Anat.* **133**: 333–340.
9. Lugaresi, E., G. Coccagna, P. Farneti, M. Mantovani, and F. Cirignotta. 1975. Snoring. *Electroenceph. Clin. Neurophysiol.* **39**: 59–64.
10. Rechtschaffen, A., and A. Kales. 1968. A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects. National Institutes of Health Publication No. 204. U.S. Government Printing Office, Washington, D.C.
11. Remmers, J. E., W. J. deGroot, and E. K. Sauerland. 1976. Upper airway obstruction during sleep: Role of the genioglossus. *Clin. Res.* **24**: 33A.
12. Sauerland, E. K., and S. P. Mitchell. 1970. Electromyographic activity of the human genioglossus muscle in response to respiration and to positional changes of the head. *Bull. Los Angeles Neurol. Soc.* **35**: 69–73.
13. Sauerland, E. K., and S. P. Mitchell. 1975. Electromyographic activity of intrinsic and extrinsic muscles of the human tongue. *Tex. Rep. Biol. Med.* **33**: in press.
14. Tonkin, S. 1974. Airway occlusion as a possible cause of SIDS. *In* "SIDS 1974: Proceedings of the Francis E. Camps International Symposium on Sudden and Unexpected Deaths in Infancy." R. R. Robinson [Ed.]. Canadian Foundation for the Study of Infant Deaths, Toronto.