Section II. Anatomy and Physiology

WILMA MAUE-DICKSON, Ph.D. (CHAIRMAN)

Introduction

This Section has been prepared for the purpose of updating the previous report, "Status of Research in Cleft Palate: Anatomy and Physiology," published in two parts in the *Cleft Palate Journal,* Volume 11, 1974, and Volume 12, 1975.

As indicated in the previous two-part report, it is imperative to consider not only the palate but all of the oral-facial-pharyngeal system, both in normal and abnormal conditions, and both in the adult and in the developing child. Thus, this review includes normal, abnormal, and developmental studies on middle ear musculature, the auditory tube, the velopharyngeal mechanism, the tongue, the larynx, the face and mandible, and blood supply and innervation relevant to cleft lip and palate. Though the relevance of embryology of the orofacial complex is obvious, it has been reviewed in a recently published report (Dickson, 1975) and will not be included as a separate topic in this review because of space limitations. Maxillary growth and development, included in the previous report, will be covered in the current report under Section III, "Orofacial Growth and Dentistry."

An effort has been made in the current report to indicate areas in which significant contributions have been made during the period reviewed as well as areas which are still seriously in need of further definitive research. As in the previous report, literature which largely reflects opinion rather than data-based conclusions has not been included.

Dr. Maue-Dickson is Associate Professor of Pediatrics, University of Miami, Mailman Center for Child Development, University of Miami, P.O. Box 52006, Biscayne Annex, Miami, Florida 33152

Middle Ear Musculature, The Auditory Tube, and The Velopharyngeal Mechanism

1. The Middle Ear Musculature

The authors of the previous report questioned the validity of the concept that the tensor tympani and the stapedius muscles provide protection to the inner ear from loud sounds, except perhaps for minimal protection (less than 10 dB) at low frequencies. They also cited research which indicated that stapedius contraction is more closely associated with voicing and coughing than with acoustic stimuli, and that the middle ear muscles might be involved in auditory tube opening.

The literature reviewed for this report does not resolve all of these questions, but it does add some focus for future research. Greisen and Neergaard (1975) used extratympanic phonometry to study middle ear reflex activity and were able to demonstrate a tensor tympani reflex in response to acoustic stimuli only when a generalized startle response was provoked. They also demonstrated that stapedius did not contract during the startle response. Like the data of Klockhoff (1959), Moller (1961), Feldman (1967) and Solomon and Starr (1963), their data indicated a close relationship between stapedial contractions and acoustic stimuli. Greisen and Neergaard observed that during the startle response, both tensor tympani and the auditory tube muscles (especially tensor veli palatini) contract and give rise to small volume displacements and subsequently to small changes in the pressure of the middle ear. They suggested that the muscles which open the auditory tube (they included levator veli palatini) may act synergistically with the tensor tympani muscle during swallowing. A similar hypothesis, *i.e.,* that the middle ear muscles and tensor veli palatini may act together in auditory tube clearance, was suggested in the previous report (Dickson, *et al.* 1974, 1975) and still seems tenable since both the tensor veli palatini and tensor tympani muscles are innervated by the fifth cranial nerve.

In summary, the consensus among the authors reviewed here is that tensor tympani responds primarily and probably exclusively to non-acoustic stimuli and that stapedius responds primarily and probably exclusively to acoustic stimuli. None of the authors reviewed presented data in support of a functional relationship between stapedius and non-acoustic stimuli or between tensor tympani and acoustic stimuli. Finally, while the question of the role of the muscle(s) of the middle ear in auditory tube clearance has still not been resolved, the data reviewed suggest that both tensor tympani and tensor veli palatini play an important role in auditory tube clearance.

As indicated in the previous review (Dickson, *et al.* 1974, 1975), the literature is replete with references to the very high and probably universal incidence of middle ear disease and hearing loss in infants born with cleft palate. While substantial efforts have been made to determine the possible role of the auditory tube in this regard, the role of the middle ear musculature still has not been investigated adequately.

2. The Auditory Tube

A number of studies on auditory tube anatomy and physiology in normal and cleft palate subjects have been published during the period of the current review. Lim (1973) published a comprehensive review of the functional morphology of the lining membrane of the middle ear and auditory tube. Koch (1963) published an excellent review of qualitative testing of auditory tube function. Misurya (1975) conducted an elegant study on the functional anatomy of the tensor palati and levator palati muscles in two dogs. Misurya's study, which essentially replicated the landmark studies of Rich (1920), demonstrated that the auditory tube canal is widened by the tensor veli palatini muscle and that maximal tubal dilation occurs toward the middle part of the canal, with less intense dilation at the pharyngeal ostium and at the isthmus. Misurya's study of the levator muscles indicated that dilation of the isthmus lumen occurs with simultaneous narrowing of the pharyngeal ostium lumen. He was careful to emphasize, however, that the levator muscle cannot be considered to be an active lumen dilator since its fibers have no direct attachment to the tube. He also demonstrated that the concavity produced by the elevation of the floor of the pharyngeal ostium is produced by contraction of the belly of the levator muscle. Misurya also successfully recorded pressure changes from anterior and posterior parts of the tube and found them to differ but also learned that the net result was no change.

The probably universal occurrence of middle ear effusion and hearing loss in babies born with cleft palate continues to be a source of concern. Glasscock (1971) has indicated that prolonged middle ear effusion may cause permanent damage to the middle ear mechanism and may result in sensorineural as well as conductive loss. Bluestone, *et al.* (1972-a, 1972-b) have provided further data on infants and children with middle ear disease which again indicates that middle ear disease is often associated with abnormalities in retrograde flow patterns through the auditory tube. His studies also suggest abnormal auditory tube distensibility associated with cleft palate. The research of Gerwat (1975) and Bluestone and Cantekin (1975) further suggests that adenoidectomy will improve auditory tube function if mechanical obstruction of the tube is present and chronic inflammation is absent (Bluestone and Cantekin) or is the degree of adenoid enlargement, though insufficient to produce total tubal obstruction, if sufficient to cause increased linear velocity of air flow with a resultant intermittent negative pressure around the pharyngeal orifice of the tube (Gerwat).

The question of the role of growth in the alleviation of middle ear disease associated with cleft palate has still not been answered. However, several studies have been published recently which bear on the question. Cole and Cole (1974) found that poor auditory tube function is not characteristic of cleft palate in the young adult age group. Their research also indicated a positive correlation between the level of observed pharyngeal wall activity and the adequacy of auditory tube function. Brooks (1975) found the incidence of middle ear effusion to be no greater in severely hearing-impaired individuals than in normal subjects at the age of 5 years. In a study of newborn infants, Keith (1975) discovered that all infants tested exhibited normal middle ear pressure and mobile middle ear systems; they appeared to have well-aerated middle ears and showed no evidence of mucous or other fluid behind the tympanic membrane.

These studies thus support the viewpoint that middle ear fluid is not characteristic of normal newborn babies and that it is no more common in cleft palate or hearing-impaired groups after the age of 5 than it is in non-cleft palate groups. Yet, as already indicated, there is ample evidence that middle ear effusion is practically universal in the newborn cleft palate group.

Obviously, then, something causes middle ear effusion to decrease in incidence or to disappear in babies with cleft palate during the first few years of life. Several studies have indicated that this may be one benefit of early corrective surgery for cleft palate (Korsan-Bengsten, 1974; Bluestone, *et al.*, 1972; Bluestone and Cantekin, 1975; and Gerwat, 1975). However, none of these studies rules out the possibility that craniofacial growth may be an important consideration in this regard and that spontaneous improvement might occur even without corrective surgery.

The latter viewpoint was expressed as a hypothesis in the research reported by Maue-Dickson, *et al.*, (1976) following a histological study of the morphology of the auditory tube and related cranial base structures in age-matched human abortuses with and without cleft palate. They found compression of all of the structures lying between the lateral walls of the pharynx and the side walls of the cranium and suggested that this could result in an alteration of the biomechanics operating on the auditory tube and that growth of the craniofacial complex may play an important role in the decreasing incidence of auditory tube malfunction in children with cleft palate during the first few years of life.

It is apparent that most of the data reported recently on auditory tube function still comes from indirect measures such as the electro-acoustic bridge, and that very little research has been done on the possible anatomical, developmental, and biomechanical factors responsible for auditory tube malfunction associated with cleft palate.

3. The Velopharyngeal Mechanism

As indicated in the previous State of the Art Report, there is a critical need for further anatomical and physiological research in the areas of normal and cleft palate to resolve questions regarding normal patterns of velopharyngeal motion, the level of motion relative to the torus tuberius, the role of specific muscles of the velum and pharynx in velopharyngeal anatomy and physiology, developmental morphology of the velopharyngeal mechanism, and the specific innervation and blood supply of muscles of the velopharyngeal mechanism. It was also pointed out in that review that descriptions of these areas are far more deficient in the area of cleft palate than in the normal condition. The current review has indicated that most of these questions still have not been resolved in spite of the many recent endoscopic, ultrasound, cineradiographic, and electromyographic studies.

A number of studies relevant to the pattern of velopharyngeal closure have been reviewed. A study of velopharyngeal competence following pharyngeal flap surgery for cleft palate was conducted by Skolnick and McCall (1972) and indicated multiple patterns for velopharyngeal closure. The authors emphasized the need for cine- or video-fluoroscopic techniques in multiple projections with simultaneous recordings of speech and roentgen images for each view. In 1973, Skolnick, *et al.* used multiview videofluoroscopy to study the mechanism of velopharyngeal closure. They did not differentiate between lateral and posterior pharyngeal wall motion since they view velopharyngeal closure as a sphincteric activity. Like Peterson (1973), Skolnick *et al.* observed that the number of different patterns in subjects with velopharyngeal incompetency is greater than in subjects with normal velopharyngeal closure. In a cinefluorographic study, Sphrintzen, *et al.* (1974) observed two and possibly three distinctly different patterns of velopharyngeal closure: pneumatic closure in speech, whistling, and blowing; non-pneumatic closure in dry swallowing and gagging; and, perhaps, reflexive swallowing. In a later study (1975) Shprintzen, *et al.* studied the first pattern further and found that the maximum medial excursion of the lateral pharyngeal walls occurred at the level of the full length of the velum and hard palate, well below the levator eminence. They hypothesized that this may be due to the select contraction of those fibers of the superior constrictor muscle which enter the velum via the lateral walls and those fibers attached to the pterygoid plates as well as to levator muscle activity.

Miyazaki, *et al.* (1975) have described fiberscopic methods for the assessment of patterns of velopharyngeal closure during various speech and non-speech activities. A fiberscopic study conducted by Matsuya, *et al.* (1974) provided further support for the already established viewpoint that velopharyngeal closure for swallow is constrictive, while that for speech involves differential degrees of movement of the velum and lateral pharyngeal walls. Matsuya also indicated that the velar and lateral pharyngeal wall motions in blowing, in which closure was achieved by " . . . posterior movement of the velum and medial movement of the lateral pharyngeal walls," are more similar to those observed in closure for speech than to those observed in swallowing. Flowers and Morris (1973) observed that some cleft palate subjects who do not achieve closure during speech do so during swallowing by the use of tongue-velar pressure and increased pharyngeal wall motion.

In 1975, Kuehn and Dolan described a new technique utilizing simultaneous frontal tomograms and lateral view x-rays for the assessment of degree and level of lateral pharyngeal wall displacement relative to the tongue, soft palate, and other structures during speech and non-speech activities. The timing and speed of velar movements relative to articulatory activity was studied cineradiographically by Kuehn (1975). He found that palatal movements were generally slower than tongue movements and that while velar velocities, displacements, and transition times showed considerable variation, depending on phonetic context and speaker, velar transitional displacements and durations were consistently reduced with increased speaking rate in both subjects. In 1976, Kuehn studied velar elevation and lowering movements and, in agreement with Kent *et al.* (1974) found that the trajectory of normal palatal movement appears to be fairly constant regardless of the magnitude or speed of movement and regardless of whether the palate is being elevated or lowered. Kuehn also found that the velopharyngeal mechanism appears to adapt to variations in speaking rate such that adequate closure is not compromised.

In 1973, Bell-Berti conducted a hooked-wire electromyographic study of various velopharyngeal muscles including the levator veli palatini, palatoglossus, palatopharyngeus, superior constrictor, middle constrictor, and sternohyoid. Her results indicated that the levator muscle is the primary muscle of velopharyngeal closure for oralization, that the amount of levator activity is correlated with the oral cavity impedance of the articulated speech sound, that nasal articulation is accomplished by suppression of electromyographic activity in those muscles participating in oral articulation, that the strength of electromyographic signals obtained from the lateral and posterior pharyngeal walls is effected by vowel color, that the pattern of velopharyngeal activity was such that it would provide an increased pharyngeal cavity volume for voiced stop consonant production, and that velar and alveolar articulation may be responsible for the increased magnitude of the electromyographic potentials from the palatoglossus, middle constrictor, and sternohyoid muscles. Bell-Berti (1975) also reported on an electromyographic study of pharyngeal size and muscle activity (levator, superior constrictor, middle constrictor, and sternohyoid) during the production of stop consonants and noted that while the feature of tension was inadequate for the description of pharyngeal volume changes concommittant with voicing distinctions, levator and sternohyoid activity was more prominent in the production of voiced stops than in the production of their voiceless cognates.

In 1973, Kewley-Port found that consistent patterns of averaged electromyographic recordings were obtained from several different electrode placements on the levator muscle, regardless of different amplitudes of the maximum scale values among them. Based on this, Ushijima and Hirose (1974) inferred that the activity pattern picked up from any one location on the levator muscle should represent the overall change in the motor command to the levator and that there are quantitatively different neural commands for movements of the velum for consonants and vowels. They also pointed out that decreased levator activity for lower vowels should not necessarily be expected to coincide with proportional decreases in absolute velar height. In an electromyographic study of these questions, Ushijima and Hirose found that the velum is not controlled by a simple on-off mechanism, that there is no systematic segmented difference between either voiced or voiceless or stop and fricative consonants, and that there are different mechanisms for anticipatory and carry-over effects of coarticulation at the level of the motor command. They also observed that there seems to be no anticipatory lowering of the velum during the vowel segments before a syllable boundary in the CVV'VN environment.

Minifie, *et al.* (1974) observed apparent inhibition of constrictor muscle activity during voiced elements and some subtle reduction during voiceless elements. They also observed comparable amplitudes of electromyographic responses from the superior and middle constrictors during swallow, but considerably less activity of the superior constrictor during speech. The middle constrictor appeared to be more active in voiced, voiceless, and vowel-consonant contexts than did the superior constrictor muscle. A correlative study of velar height and levator activity using hooked-wire electrodes was conducted by Ushijima and Hirose (1974). The authors felt that increased electromyographic activity on consonants following nasals indicated increased strength of contraction needed to achieve closure, as opposed to increased maximum velar height or tighter velopharyngeal closure.

Zagzebski (1975) measured the degree of lateral pharyngeal wall motion during speech with ultrasound and found greater medial displacements at the level of velopharyngeal closure than at the level of the angle of the mandible, greater displacement for low vowels than for high vowels at the level of the angle of the mandible, and greater lateral wall motion for non-nasal sounds than for nasal sounds at the level of the velopharyngeal closure. He challenged the hypothesis of Dickson (1972) that the levator action at the level of the torus tuberius is responsible for maximum mesial movement of the lateral pharyngeal walls during speech, and offered support for the data of Shprintzen (1974), which indicated that maximum mesial wall motion occurs well below the levator eminence.

An excellent discussion of the advantages and disadvantages of the use of ultrasound was provided by Ryan and Hawkins (1976). They pointed out that while ultrasound is comfortable, safe as compared with x-ray, low in cost, and portable, it may be time-consuming and recordings may be difficult to interpret accurately. In addition, variable thickness of the trace may introduce serious errors in displacement measurements, and interpretation is jeopardized by a dearth of normative data.

In 1976, Zwitman, *et al.*, conducted an oral telescope and radiographic study of velar and lateral pharyngeal wall motion which indicated that absent or restricted lateral wall motion was more common in the subjects with cleft palate.

The size of the velopharyngeal aperture

in cleft and non-cleft palate speakers with significant degrees of hypernasality was studied with lateral x-rays by Carney and Morris (1971). They found the two groups to be very similar in the frequency and magnitude of closure and in the lack of correlation between severity of hypernasality and the degree of velar constriction, pharyngeal constriction, oral constriction, and incisor opening. They concluded that the critical size of velopharyngeal opening is variable and does not appear to be useful in describing the relationship between the severity of nasality and degree of velopharyngeal opening. It seems obvious that the critical size of velopharyngeal opening depends in large part on phonetic context and on the relative levels of oral and nasal impedance. This was demonstrated by Benson (1972) in a roentgenographic cephalometric study of velopharyngeal closure during vowel formation. Benson demonstrated that a residual velopharyngeal lumen is present in 62 per cent of normal individuals phonating /a/, 23 per ient phonating /i/, and 9 per cent phonating /u/. Measurements of mean palatal height during velopharyngeal closure further supported these findings. Posterior pharyngeal wall motion in normal individuals was found to be minimal during vowel production and the atlas was found to be too variable to be a dependable landmark in the assessment of velopharyngeal closure.

As indicated in the previous review, the velum is longer during velopharyngeal closure than during rest. Simpson and Austin (1972) used lateral x-rays to study velar stretch during rest and during the phonation of /s/, and found that, while significant stretch occurred for the entire velum during velopharyngeal closure, the posterior portion exhibited a greater degree of stretch than did the anterior portion, and that, during stretch, the anterior portion decreased in thickness while the posterior portion increased in thickness. They also indicated that stretch in the anterior portion appeared to be related to the degree of structural adequacy of the velopharyngeal mechanism while that in the posterior portion did not. They hypothesized that the levator muscle is responsible for the changes observed in the anterior portion while the uvulus muscle is responsible for changes in the posterior portion. This fits well with the anatomy of the levator as described by Dickson (1972) and the anatomy of the uvular muscle as recently described by Langdon (1976).

Only two studies of motor nerve supply to the velopharyngeal musculature were found (Nishio, *et al.* 1976; and Nishio, *et al.* 1976). Both were conducted on rhesus monkeys. By direct stimulation of various cranial nerves within the skull, the authors obtained data which indicated that the levator, uvulus, and superior constrictor muscles received double innervation via the facial nerve and via branches of the pharyngeal plexus derived from the glossopharyngeal and vagus nerves and that the facial nerve played an important role in velopharyngeal closure. Using a nasopharyngeal fiberscope and photographic equipment to record the results of direct nerve stimulation, they observed that velopharyngeal movements were the most active on stimulation of the vagus, less active on stimulation of the glossopharyngeal, and least active on stimulation of the facial nerve. Complete closure by unilateral nerve stimulation was elicited only by the vagus, though in some cases, velopharyngeal closure was also achieved by bilateral stimulation of the seventh cranial nerve. Combined stimulation of the three nerves (VII, IX, and X) sometimes resulted in an additive effect. The authors concluded that the motor nerves innervating the velopharyngeal muscles play different roles in velopharyngeal movements. Motion observed on stimulation to the vagus or glossopharyngeal nerve was similar to that observed in swallowing in human subjects, while stimulation to the facial nerve resulted in velopharyngeal motion similar to that observed in phonation in human subjects. It should be noted that innervation equivalence between the rhesus monkey and man has not yet been demonstrated.

In summary, the studies reviewed for the current report support previous data indicating that the patterns of velopharyngeal closure differ for speech and for swallowing (Flowers and Morris, 1973; Matsuya, *et al.*, 1974; and Minifie, *et al.*, 1974), while the patterns for speech and blowing are similar (Matsuya, *et al.*, 1974; Shprintzen, *et al.*, 1974). Degree, strength, and pattern of velopharyngeal closure; degree and level of the lateral pharyngeal wall movement; and rate and timing of velar and tongue movements during speech activities appear to depend on specific speech environment, e.g., low or high vowels, nasal or non-nasal sounds, and speaking rate (Benson, 1972; Ushijima and Hirose, 1974; Kent, 1974; Zagzebski, 1975; Kuehn, 1975, 1976; and Minifie, *et al.* 1974).

A challenge has been offered to Dickson's (1972) hypothesis that the maximum mesial movement of the lateral pharyngeal walls during velopharyngeal closure for speech occurs at the level of the torus tubarius and is produced by the levator palati muscle (Skolnick, *et al.* 1973; Shprintzen, *et al.*, 1975; and Zagzebski, 1975). The consensus on velopharyngeal closure patterns is that they are variable but are more variable in velopharyngeal incompetence than in normal conditions (Carney and Morris, 1971; Skolnick and McCall, 1972; Skolnick, *et al.*, 1973; Peterson, 1973; Shprintzen, *et al.* 1974; and Zwitman, *et al.* 1976).

With regard to the role of specific muscles in velopharyngeal activity for speech, Simpson and Austin (1972) hypothesized that anterior velar stretch in velopharyngeal closure may be related to levator activity while posterior velar stretch is probably related to uvular muscle activity. Shprintzen (1975) hypothesized that the maximum medial excursion of the lateral pharyngeal walls, which he observed to occur at the level of the full length of the hard palate and velum, may be due to select contraction of the upper fibers of the superior constrictor muscle as well as to the levator muscle. Minifie, *et al.* (1974) suggested some degree of inhibition of the superior constrictor muscle during speech with more activity of the middle constrictor muscle than of the superior constrictor muscle in the production of voiced-voiceless and vowel-consonant contrasts.

Bell-Berti (1973, 1975) presented electromyographic data which again indicated that the levator veli palatini muscle is the primary muscle of velopharyngeal closure for oralization. Further elucidation of velopharyngeal activity was provided by the electromyographic studies of Kewley-Port (1973) and Ushijima and Hirose (1974).

Shelton and Trier (1976) presented a review which summarized the problems of fluoroscopic examination of velopharyngeal closure and addressed serveral important issues, including procedural problems in the fluorographic examination of the velopharyngeal mechanism and the need for non-fluorographic measures and for validation of measures.

The Tongue and Facial Musculature

Only one study of normal anatomy of the intrinsic lingual musculature was found (Barnwell, 1975). The author conducted a nicely designed study of the styloglossus muscle in one cadaveric adult tongue, utilizing micro-dissection, and in fourteen 15-week human abortuses, utilizing serial histologic sections. She demonstrated that the styloglossus muscle originates either from the styloid process or from the sphenomandibular ligament and that it then courses anteriorly, medially, and inferiorly to the lateral border of the hyoglossus muscle at the base of the tongue. Here it divides into two sections: a posterior bundle which turns medially to terminate at the lateral border of the genioglossus muscle and an anterior bundle which courses to the tip of the tongue lateral to the hyoglossus muscle and inferior to the palatoglossus and superior longitudinal muscles. In the anterior third of the tongue, styloglossus fibers were found to converge with fibers of the hyoglossus and inferior longituidinal muscles, and, in fetal specimens, with oblique fibers rising from the lamina propria. The author also found the styloglossus to vary in bulk, length, and symmetry.

Only two additional anatomical studies of the tongue were found. Soames (1973) conducted a histologic study of 100 cadaveric tongues and found no evidence of either the thyroglossal duct or of thyroid tissue but did find that lymphoid tissue was present in association with the epitheliumlined pit in half of the cases studied. Mucous and serous glands were present in all cases but showed no regular pattern of distribution. Fletcher and Daly (1974) measured sublingual dimensions in 50 children. Based on their data, the authors suggest several "rules of thumb" for the identification of tongue-tie: inability of a child to raise his tongue tip to contact the alveolar ridge, to move a protruded tongue from one corner of the mouth to the other, or to achieve contact for linguadental and lingua-alveolar consonants; a "notching" of the tongue when the tongue tip is protruded; or sublingual restriction that prevents the tongue from being protruded beyond the lower gum.

No studies of lingual anatomy in cleft palate were found in the current review. However, in an experiment in mobilization of the palatine bones of cleft dogs, Latham and Smiley (1973) picture, but do not describe, a coronal histologic section through the head of a 17-week human abortus with complete cleft of the secondary palate. The tongue configuration appears to be abnormal and is identical in gross character to similar sections from fetuses with cleft palate examined by the author. There is clearly a need for further study of lingual anatomy associated with clefts of the palate.

The specific morphology of the orbicularis oris muscle in normal and cleft palate subjects is still a subject of interest. Several early reports on this muscle in the child with cleft lip not reviewed in the previous report have been found as well as several more recent reports. In 1946, Lee described the orbicularis oris muscle from histologic sections in a five-month old negroid female child with a bilateral cleft lip and cleft palate. Contrary to the usual textbook descriptions of this muscle in the normal adult, he found no concentration of purely sphincteric muscle fibers at the corner of the mouth. Instead, the orbicularis oris muscle was found to consist primarily of a heavy mass of horizontal fibers, which extended close to the free border of the lip, and of only relatively few sphincteric muscle bundles. The fibers of the muscle thinned out and fragmented markedly as they approached the ala of the nose. Rees (1962) examined the contents of the prolabium via tissue biopsies from 15 patients with cleft lip. Sections prepared from these biopsies indicated that muscle tissue was absent or markedly diminished in all cases and that normal muscle bundle architecture was not present. Three additional tissue biopsies from "older children" with unoperated complete bilateral clefts were also found to contain no muscle tissue. In addition, the authors collected electromyographic recordings from the prolabia of four subjects with secondary bilateral clefts. None showed normal action potential, indicating that the motor units in these prolabial segments were either sparse or absent. The authors observed that incomplete clefts of the lip are characterized by relatively more muscle tissue than are complete clefts although the tissue is still not normal in amount or function. The absence of anatomically and functionally significant muscles in the prolabium in bilateral clefts of the lip was also observed by Duffy (1971), who found that muscle tissue in the philtrum probably comes exclusively from the lateral segments in normal development.

Several excellent electromyographic studies of normal lingual musculature, both extrinsic and intrinsic, and of normal facial musculature have been published during the current review period. In 1974, Bell-Berti and Harris investigated the electromyographic activity of the genioglossus muscle in three normal English speakers in an attempt to identify instances of anticipatory coarticulation at the motor command level. Their hypothesis was that electromyographic activity would merge for sequences moving toward a more closed vocal tract. They found that, when the sequence involves moving from a more open to a less open vocal tract, only one peak of electromyographic activity is present. However, when the reverse motion is observed, two separate peaks of electromyographic activity occur.

Miyawaki, *et al.*, (1975) published a preliminary report on an electromyographic study of the activity of lingual muscles in one adult subject. They utilized hooked-wire electrodes inserted perorally and percutaneously at five different locations on the genioglossus muscle and made sound recordings simultaneously during the experimental speech tasks. They also dissected and stimulated four twigs of the twelfth cranial nerve supplying the medioposterior fibers of the genioglossus muscle in a dog. It was observed in the latter part of the experiment that the stimulation of a twig caused a distinctly localized contraction of a limited portion of the genioglossus muscle. The authors felt that these findings supported observations on human subjects that electromyographic signals recorded simultaneously from different locations on the genioglossus muscle differed characteristically in their active patterns and, therefore, that genioglossus consists of a number of components or subdivisions capable of contracting separately. They also indicated that the genioglossus muscle is active for vowels characterized by "high" and/or "front" positions, while it shows little activity for vowels which are neither high nor front. The question of validity in this study needs further attention. While there is little consensus in the literature regarding the specific function of any of the extrinsic and intrinsic lingual muscles in man, the authors enumerate the functions of the anterior belly of the digastric, the geniohyoid, the styloglossus, the genioglossus, and the transverse and superior longitudinal muscles of the human tongue.

Raphael (1974) conducted a concentric-needle electromyographic study simultaneously with voice output recordings on vowels preceding voiced and voiceless consonants in English with two subjects. Muscles recorded included the orbicularis oris, depressor anguli oris, inferior longituidinal, mylohyoid, and genioglossus. Their results indicated the possibility of sustained muscular activity in the articulatory gesture for vowels preceding voiceless consonants. They also noted that acoustically determined differences between duration of muscular-articulatory gestures for the vowels and temporal displacement of the final consonant peaks generally showed very similar values.

Fischer-Jorgensen and Hirose (1974) conducted a hooked-wire electromyographic study of labial and lingual musculature in labial stop consonant production in Danish speakers. Specific muscles studied included the orbicularis oris superior and inferior muscles, the depressor anguli oris, the depressor labii inferioris, and various laryngeal muscles. They found that orbicularis oris superior and inferior both showed strong activity during lip closing, while strong orbicularis oris inferior activity occurred during lip rounding.

Gay (1974) studied the effect of speaking rate on the articulation of the consonant-vowel articulation in two normal adult male speakers. By the simultaneous use of high-speed lateral view x-rays of the tongue and jaw and electromyographic recordings from muscles which control lip, tongue, and jaw movements, he was able to demonstrate that, for labial consonant production, increased speaking rate is accompanied by increased activity of the orbicularis oris muscle and slightly increased rates of lip movement. Conversely, as speaking rate was increased, vowel production was accompanied by decreased genioglossus activity and evidence of target undershoot. Jaw displacement was generally decreased during fast speech, a finding inconsistent with the observations of Abbs (1973), who found little effect of speaking rate on jaw displacement.

Only one study relevant to human lingual innervation was found. Borden and Harris (1973) conducted an electromyographic study of speech under trigeminal nerve-block anesthesia. Tongue muscles studied included the genioglossus, geniohyoid, and superior longitudinal. The significance of their conclusions is the assumption that the effects of the traditionally used nerve-block are purely sensory. The authors observed that other muscles were either depressed during the block or more active than normal and suggested that the electromyographic amplitude recorded depends on the depth of anesthesia and upon idiocyncratic reactions of the subjects. They observed that changes in muscle activity during the nerve-block extended even to those muscles whose sensory and motor nerves cannot be affected by the block and, therefore, suggested that the effects observed indicate a more central effect or some compensatory reorganization. They found that muscles innervated by the blocked nerve were consistently depressed or inactive. Thus, despite attempts to anesthesize only the lingual nerve, the anesthesia must have infiltrated. They also found that muscles presumably associated with sensory fibers from the blocked nerve and those which should be independent of the blocked nerve behaved erratically.

No definitive studies were found on lingual blood supply or developmental anatomy. Neither were any studies found which compared lingual anatomy in cleft palate with the normal condition even though there are strong suggestions that a difference in lingual anatomy does exist between these two groups.

In summary, very little work has been done during the current review period on the anatomy of the tongue or facial musculature either in normal individuals or in individuals with cleft palate. Several articles published prior to 1972 were found on anatomy of the orbicularis oris muscle in cleft lip and palate (Lee, 1946) and on the prolabium in cleft lip (Rees, 1962; Duffy, 1971). Recent electromyographic studies on labial, lingual, and facial musculature have added new information on co-articulatory gestures, muscle function, and motor control of speech. Bell-Berti and Harris (1974) indicated that genioglossus activity is different for speech sequences involving movement from a more open to a more closed vocal tract than for the reverse condition. Miyawaki, *et al.* (1975) found strong genioglossus activity during high and front vowel production. Raphael (1974) found some evidence for sustained muscular activity in the articulatory gestures for vowels preceding voiceless consonants. Fischer-Jorgensen and Hirose (1974) found that both the orbicularis oris superior and inferior muscles were active during lip closing while only the inferior muscle showed strong activity during lip rounding. Gay (1974) found that increased speaking rates were associated with decreased jaw displacement, increased levels of orbicularis oris activity, and increased rates of lip movement. Finally, only two studies relevant to lingual innervation, one human and one on the dog, were found (Borden, *et al.* 1973; and Miyawaki, *et al.* 1975).

The Larynx

Very few studies have been published recently on developmental morphology, adult structure, or function of the human larynx, and only two of these concern the individual with cleft palate. Too-Chung and Green (1973) reported a study of cricoid cartilage dimensions in post-mortem specimens ranging in age from neonatal to 15 years in which they found that the child's cricoid cartilage is typically elliptical with the coronal diameter greater than the sagittal, that cricoid growth rate in these two dimensions relative to body weight is linear, and that the primary predictive value for cricoid area was weight. They did not find any significant sex differences. In 1975, Kahane conducted a study of the morphology of the circumpubertal human larynx. He found that, with the possible exception of width and posterior height of the arytenoid cartilage, none of the sex differences observable in adult male and female larynges were present in the prepubertal group but that all were present in the pubertal group. Growth of the larynx was found to be linearly related to growth in body height but was less well related to chronological age.

Several studies of laryngeal muscular activity were reported during the current review period. Gay, *et al.* (1972) studied intrinsic laryngeal muscle formation electromyographically during phonation. The authors found that, in general, increases in fundamental frequency were accompanied by progressive increases in the activity of the cricothyroid and vocalis muscles, that the posterior cricoarytenoid activity increased at high fundamental frequencies, that muscle activity pattern was the same at both low intensity and high intensity, and that in general higher frequency steps were characterized by only slight increases in adductor activity. In describing increased posterior cricoarytenoid activity at high fundamental frequencies, the authors state that posterior cricoarytenoid may act as a tensor of the vocal folds. They also described the cricothyroid and vocalis muscles as primary in the control of fundamental frequencey and demonstrated that activity of the vocalis muscle, and often of the cricothyroid, decreases in a shift from chest voice to falsetto.

A second hooked-wire electrode study conducted by Hirose and Gay (1972) indicated posterior cricoarytenoid activity for voiceless consonants and suppression of its activity for voiced consonants, while the reciprocal pattern was observed for the interarytenoid muscle. It was observed by the authors that the posterior cricoarytenoid activity did not follow an all-or-none type pattern and that the interarytenoid showed less activity for voiced fricatives than for vowels. Hirose and Gay (1973) also conducted an electromyographic study of laryngeal control in vocal attack of three types: breathy or aspirate, soft or simultaneous, and hard or glottal. Each type was found to be characterized by coordinated or reciprocal action of the abductors and adductors, although the timing was different in each. In breathy and aspirate attacks, the posterior cricoarytenoid was found to remain active throughout the prephonatory period up to the point immediately preceding phonation. As the posterior cricoarytenoid shut down, interarytenoid, vocalis, lateral cricoarytenoid, and cricoarytenoid activity was found to increase abruptly. In hard attacks, however, the posterior cricoarytenoid activity was found to decrease earlier and the lateral cricoarytenoid activity was found to increase earlier, while the interarytenoid, vocalis, and cricothyroid also showed prephonatory activity followed by a fall. In soft attacks, the posterior cricoarytenoid activity was found to be suppressed during the prephonatory period while activity of the adductors and the cricothyroid increased steadily reaching a peak after the onset of voicing.

As a part of their electromyographic study of labial and laryngeal muscles in stop consonant production, Fischer-Jorgensen and Hirose (1974) studied the interarytenoid, posterior cricoarytenoid, thyroarytenoid (vocalis), lateral cricoarytenoid, and cricothyroid muscles in six Danish speakers. They found that the activity of the interarytenoid was strong when the preceding consonant was accompanied by a large glottal opening. Previous work by the authors had suggested that the vocalis and lateral cricoarytenoid were generally active during vowels and inactive during consonants. Their current research indicated a far more complex but still not completely deciphered pattern of activity. Hirose, *et al.* (1974) investigated laryngeal control in Korean stop production. Their results indicated that, at least in Korean stops, laryngeal articulatory activity is not limited to simple adduction/abduction of the vocal folds. Hirose and Ushijima (1974) also studied the function of the posterior cricoarytenoid muscle during speech. They found that glottal opening for word-medial voiceless stops and geminates is generally smaller than for voiceless frictatives or devoiced vowel segments and that the degree and timing of posterior cricoarytenoid activity are directly responsible for determining the size and temporal course of glottal opening for voiceless segments. They noted that suppression of the adductors may also have to be considered for a complete description of voiceless segment production.

Collier (1974) assessed the degree to which laryngeal activity and subglottal air pressure affect the rate of vocal fold vibration in speech. Electromyographic and subglottal air pressure recordings made simultaneously suggested that the gradually falling baseline of a fundamental frequency contour is controlled by the slowly decreasing subglottal air pressure while major deviation from this baseline is caused by cricothyroid muscle activity. Increased cricothyroid activity was found to raise the fundamental frequency. Sustained contraction maintained high fundamental frequency, and relaxation lowered fundamental frequency.

Five studies of laryngeal innervation were found in the current review. Wyke (1974) suggested that the precise control evident in laryngeal activity results from three reflexogenic systems (mucosal, articular, and myotatic). He studied the latter in cats and in man. His findings indicated the presence of sparsely distributed muscle spindles, "relatively small in size," and numerous spiral nerve endings, which he concluded were probably the primary mechanoreceptors. His conclusions regarding human mechanoreceptor activity must be considered to be hypothetical since his experimental work with electromyography was on cats.

In a study of the ganglion of the internal laryngeal nerve, Ramaswamy and Kulasekaran (1974) dissected or sectioned larynges from human abortuses and from cadavers ranging in age from 12 to 66 years. Their findings established the presence of single bilateral ganglia in the majority of specimens studied and of two or more masses in several cases. The ganglion, located on the internal laryngeal nerve at the level of the saccule, exhibited cell structure which was multipolar with eccentric nuclei, suggesting parasympathetic function, e.g., stimulation of the glands of the saccule for lubrication of the vocal folds.

Based on a study of the internal branch of the superior laryngeal nerve during and after its anesthetization, Tanabe, *et al.* (1975) hypothesized that this nerve may play an important role in precise control of fundamental frequency without, however, affecting overall or gross control of phonation.

Kratz (1973), in a description of a new microsurgical technique for the identification and protection of the laryngeal motor nerves during thyroid and laryngeal surgery, described the location and position of the recurrent laryngeal nerve in over 100 surgical exposures of the nerve. He found that the recurrent laryngeal nerve always divides before entering the larynx but that the divisions are sometimes so close together that they might not seem separate to the naked eye.

Malannino (1974) conducted a histologic study of neuromuscular spindles in the posterior cricoarytenoid and thyroarytenoid muscles in human abortuses and pointed out that evidence of spindles in such a group of early developing embryos confirms the considerable role of intermuscular coordination within the laryngeal musculature.

Pearson (1975) conducted an elegant study of human laryngeal microcirculation in 20 normal adult human larynges by microdissection and serial sectioning after clearing of soft tissues and opacification of arterial and venous circulation. He found that mucosal capillary beds exhibited random orientation in the epiglottis, ventricular folds, and ventricles, that capillaries of the vocal folds lay parallel to the folds, that subglottic capillaries radiated from the anterior commissure, and that posterior cricoid capillaries ran longitudinally from superior to inferior. Muscles tended to be supplied from their margins by tortuous arterioles of the nearby vessels, and longituidinal capillary beds branched from their vessels in the long axis of the muscle fibers. The cartilage was found to be avascular while the perichondrium was found to be distributed uniformly with fine interconnecting arterioles. Vessels were observed to penetrate to all sites of ossification. Finally, it was found that deeper arterioles and arteries of the submucosa supply the epiglottus from its periphery with its midline area remaining less vascular.

Several studies of laryngeal function relevant to cleft palate subjects have also been published recently. Hamlet (1973) conducted an ultrasound study of vocal fold vibration during the production of hypernasal sounds and found that the open quotient of the vibratory cycle is generally lower for nasalized vowels than for nonnasalized vowels. Lowry, *et al.*, (1974) used a laryngeal mirror to examine the larynges of 74 children with cleft palate. Seventy-two of the children exhibited normal larynges; one had thickened edematous and reddened vocal folds; and another appeared to have very short vocal folds in the anteroposterior dimension. However, no attempt was made to correlate these findings with a non-cleft palate control group or with acoustic observations (e.g., hoarseness). McWilliams, *et al.* (1973) published a report on vocal fold abnormalities in 27 children with borderline velopharyngeal valving problems which indicated that vocal fold pathology, particularly vocal nodules and hoarseness, were common occurrences in this group. The authors indicated that increment in chronological age is the most important single factor in the remission of vocal pathology and that surgical removal of vocal nodules is usually insufficient unless it is accompained by correction of the velopharyngeal valving problem.

Laryngeal embryology continues to be a largely unexplored area. Tucker and Tucker (1975) cited the stages at which specific laryngeal structures are identifiable. They also pointed out, once again, the problem of aging human embryos and fetuses because of variations in growth rate and the rarity of accuracy of the mother's report of last mensus as a predictor of the date of conception. They challenged the validity of the view that the fetal period merely represents an extension of maturation of the dynamics of the embryonic stage and reiterated the urgent need for a significantly large, closely graded, well-documented series of fetal larynges which could perhaps be obtained via the pooling of resources.

In summary, only two studies (Too-Chung and Green, 1973; and Kahane, 1975) were found of laryngeal cartilage dimensions. Both studies suggested a lack of prepubertal sex differences. Several significant studies of laryngeal anatomy have been reported recently. Wyke (1974) demonstrated the presence of sparsely distributed neuromuscular spindles and numerous spiral nerve endings in various laryngeal muscles. Malinnino (1974) found neuromuscular spindles in the posterior cricoarytenoid and thyroarytenoid muscles of human larynges and linked their presence with intermuscular corrdination. Kratz (1973) described the anatomical location of the recurrent laryngeal nerve. Ramaswamy and Kulasekaren (1974) described the internal laryngeal nerve ganglia as typically single bilateral structures which are probably parasympathetic in function. Human laryngeal microcirculation was described in detail by Pearson (1975).

Several significant studies of laryngeal physiology have also been published recently. The posterior cricoarytenoid muscle has been studied electromyographically by Hirose and Gay (1972), Fischer-Jorgensen and Hirose (1974), and Hirose and Ushijima (1974). In these studies, it was shown to be active for voicless consonants but suppressed for voiced consonants and to be important in determining the size and timing of glottal opening for voiceless segments. The interarytenoid muscle seems to be more active for vowels than for voiced fricatives (Hirose and Gay, 1972) and more active after consonants with large glottal openings than after those with small glottal openings (Fischer-Jorgensen and Hirose, 1974). The vocalis and cricothyroid muscles again have been linked with control of fundamental frequency (Gay, *et al.*, 1972; Collier, 1974). It is apparent that laryngeal articulatory activity is not limited to simple abduction/adduction maneuvers of the vocal folds (Hirose, *et al.*, 1974), and it has been demonstrated that timing of the reciprocal activity of the abductors and adductors is different for breathy, soft, and hard vocal attacks.

Two studies reviewed (Lowry, *et al.*, 1974; McWilliams, 1973) dealt with vocal fold problems in cleft palate. Lowry found that the vast majority of cleft palate subjects examined had normal larynges while McWilliams found vocal pathologies to be a common occurrence.

Hamlet (1973) studied vocal fold vibration during the production of hypernasal vowels and found the open quotient to be lower than for non-nasalized vowels.

Finally, Tucker and Tucker (1975) have reiterated the need for further fetal laryngeal research with significantly large and closely-graded specimen series.

It is clear that there is a very real need for further definitive research on laryngeal anatomy, physiology, and developmental morphology in normal individuals. In the area of cleft palate, the need remains urgent.

Craniofacial Innervation and Blood Supply

The current section will cover only those areas of innervation and blood supply not specific to areas previously discussed in this report.

Freeland and Rogers (1975) studied the vascular supply of the cervical skin with colored silicon rubber injections on abortuses and adult cadavers. They found that the skin of the neck anterior to the trapezius muscle is supplied by descending branches of the transverse cervical and supracapular arteries. These branches were found to pierce the platysma where they anastomose to form a fine superficial network of vessels which also run in a vertical direction. The venous drainage was found to run in a descending direction at all levels of the cervical skin. Allen, *et al.* (1973) provided an excellent and detailed description of the anatomy of the maxillary artery. Storrs (1976) described the course of the stapedial artery and pointed out that most of the craniofacial anomalies which have been reported concern the persistence of this artery. Baumel (1974) has provided an extensive (90 reference) review of the literature on trigeminal-facial nerve communication which deserves to be read in its entirety by those interested. Pon (1976) gave a description of anomalies of the facial nerve and middle ear ossicles. White and Verma (1973) conducted a study of the spatial arrangement of facial nerve fibers in 15 human temporal bones which indicated that the nerve shows two main divisions which divide dichotomously to send fibers to both the upper and lower face. In addition, they found a free mixing of fibers by several anastomosing branches between the two primary divisions. Borden, *et al.* (1973) used bilateral mandibular nerve blocks in a study designed to determine whether or not skilled speech is an open-loop system requiring little or no feedback from the periphery or a closed-loop system requiring sensory information to control the production of speech. Their findings indicated that the effect of nerveblocking is subtle, limited, and manifested only in rapid connected speech. The effect was limited to /s/, /z/, /f/, /t/, /r/, and /l/. They concluded that, " . . . The high degree of intelligibility of all of the speakers in the study gives some weight to the theory that skilled speech may be largely under open loop control," and they stated that, " . . . It may be that the oral sensory system used to monitor speech is of primary importance only during the learning of speech."

Abbs (1973) used a special application of nerve block anesthesia which presumably suppressed gamma efferent fibers while leaving alpha efferent fibers unaffected. He measured jaw displacement, velocity, and acceleration under both normal and gamma block conditions in two normal subjects. Their data suggested that, under gamma block conditions, disruption or absence of spindle afferent facilitation to alpha motoneurons occurs. The author suggested that under normal conditions the spindle motor system operates more clearly under conditions of movement in which large values of acceleration, velocity, and displacement are required. He also suggested that the spindle motor system is important in orofacial movements during the production of speech.

Finally, one study published prior to the current review period but not found in the previous State-of-the-Art review should be cited. King (1954) conducted an extremely inciteful and elaborate study of both the blood supply and innervation of the craniofacial complex in four human abortuses. He dissected the face in one normal full-term abortus and in one full-term abortus with a complete bilateral cleft of the lip and palate. He also histologically sectioned and analysed the same area in a normal seven-month-old abortus and in a second full-term abortus with a complete bilateral cleft of the lip and palate. Only a brief summary of his findings is given here. He found that the sockets for the incisor teeth were more shallow in the cleft specimen and that, while the subvomerine processes were present, there were no facial or palatal processes. The arterial supply of the main tubercle was found to be derived from the left facial artery via the arching trunk which crossed the nasal bone to reach the midline and then transversed the columna naris and philtrum. The veins exhibited similar arches but emptied into the anterior facial veins on both sides. Large trunks of the intraorbital nerves traveled with the anterior trunk to reach the median tubercle. The incisors had a "copious blood supply" from the facial arch but no nerve supply, and the anterior dental nerves, after transversing the maxillae, joined the intraorbital trunks. The author discussed the normal development of the philtrum and premaxillary region in light of the cleft specimens studied and stated that in abnormal conditions the nerves may wander far from their normal sources. He also stated that the distribution of sensory nerves cannot be used with confidence in the determination of the embryonic origin of adult tissues.

Summary and Discussion

Regarding middle ear musculature, the current consensus is that tensor tympani responds primarily and probably exclusively to non-acoustic stimuli and that stapedius responds primarily and probably exclusively to acoustic stimuli. The role of the middle ear muscles in auditory tube clearance has still not been resolved, but there are some data which suggest that the tensor tympani works with the tensor veli palatini in this function. Thirdly, the role of the middle ear musculature in middle ear disease, particularly in cleft palate, has not been determined and clearly needs further study.

There is convincing evidence that middle ear effusion is probably universal in newborn infants with cleft palate. Recent studies have indicated that fluid is not present at birth in normal infants and that by the age of five years it is no more common in cleft palate or hearing impaired groups than it is in normal groups. The reasons for the apparent decrement in the extremely high incidence of middle ear effusion in the cleft palate groups during the first few years of life have not yet been determined and need further study. It has been suggested that palatal surgery, adenoidectomy in selected cases, and growth may be important factors in this regard. Since the trends seem to be the same in operated and unoperated groups, the major corrective factor may well be growth of the craniofacial complex during the first few years of life.

There are still numerous questions which need to be answered regarding velopharyngeal anatomy in both normal and cleft palate individuals. There are no final answers as yet regarding normal patterns of velar and lateral pharyngeal wall activity, level of activity, sex differences, or specific innervation and blood supply to the velopharyngeal complex. It does seem clear that patterns of velopharyngeal closure for speech and blowing are similar to each other but differ substantially from those observed in biologic closure. A major problem in the investigation of these questions is still both a basic science and a technical issue. Specific muscular anatomy and physiology is still not well understood, and, therefore, validation of electrode placement in electromyographic studies and correct interpretation of cineradiographic and ultrasonic recordings continues to be a source of concern. Rate and timing in velopharyngeal closure in speech and non-speech activities lacks definitive description.

Our understanding of the tongue is still vague. More studies like that of Barnwell (1975) on specific lingual muscular morphology must be conducted before definitive electromyographic studies of individual human lingual muscles can be done. No definitive works on lingual innervation or blood supply have been reported recently in either normal or cleft palate groups.

Several electromyographic studies have added to our information on laryngeal physiology, but, as in velopharyngeal and lingual research, validation of electrode placement continues to be a problem because of the lack of definitive information about muscular anatomy. There is conflicting information on the prevalence of laryngeal pathology in cleft palate individuals, and the studies which have been done have served primarily to emphasize the need for further investigation in this area.

It also seems apparent that more attention must be paid to the limitations, validation, and multiple-approach use of many of our research tools. Too often in the research reviewed, it seemed probable that results were too "Tool-specific" and too "subject-specific."

As a general comment, there have been few studies of the craniofacial complex which have dealt with questions of variability in normal or cleft palate populations. There is still an urgent need for well-designed developmental studies in all areas reviewed. Finally, there does not seem to be much interdisciplinary "pooling" of data.

Part of the summary of the previous State of the Art Report bears repetition: There is an urgent need for further anatomical research in all areas of the craniofacial complex; more complete normative data is needed in order to support the study of pathologic conditions; there is a need for the coordination of anatomical and physiological research; and there is a need for interdisciplinary research.

References

ABBS, J. H., The influence of the gamma motor system on jaw movements during speech: a theoretical framework and some preliminary observations, *JSHR 16,* 175–200, 1973.

BARNWELL, Y., The morphology of musculus styloglossus in the human fifteen-week fetus, Unpublished Ph.D. thesis, University of Pittsburgh, 1975.

BELL-BERTI, F., The velopharyngeal mechanism: an electromyographic study, *Haskins Labs.,* status report on speech research, suppl., 1973.

BELL-BERTI, F., Control of pharyngeal cavity size for English voiced and voiceless stops, *J. Acoustic Soc. 57,* 456–461, 1975.

BELL-BERTI, F., and HARRIS, K. S., More on the motor organization of speech gestures., *Haskins Labs.,* status report on speech research, *SR* 37–38, 1974.

BENSON, D., Roentgenographic cephalometric study of palatopharyngeal closure of normal adults during vowel phonation, *Cleft Pal. J. 9,* 43–50, 1972.

BLUESTONE, C. D., PARADISE, J. L., and BEERY, A. C., Physiology of the eustachian tube in pathogenesis and management of middle ear effusions, *Laryngol. 82,* 1654–1670, 1972.

BLUESTONE, C. D., WITTEL, R. A., and PARADISE, J. L., Roentgenographic evaluation of eustachian tube function in infants with cleft and normal palates, *Cleft Pal. J. 9,* 93–100, 1972.

BLUESTONE, C. D., PARADISE, J. L., BEERY, Q. C., and WITTEL, R., Certain effects of cleft palate repair on eustachian tube function, *Cleft Pal. J. 9,* 183–193, 1972.

BLUESTONE, C. D., CANTEKIN, E. I., and BEERY, O. C., Certain effects of adenoidectomy on eustachian tube ventilatory function, *Laryngoscope 85,* 113–127, 1975.

BORDEN, G. J., HARRIS, K. S., OLIVER, W., Oral feedback, I. Variability of the effect of nerve-block anesthesia upon speech, *J. Phonetics 1,* 297–398, 1973.

BROOKS, D. H., Middle ear effusions in children with severe hearing loss, New York, American Electromedics Corp, Impedence Newsletters, *4,* (no year given, probably 1975).

CARNEY, P. J., MORRIS, H. L., Structural correlates of nasality, *Cleft Pal. J., 8,* 307–321, 1971.

COLE, R. M., COLE, J. E., Eustachian tube function in cleft lip and palate patients, *Arch. Otol. 99,* 337–341, 1974.

COLLIER, R., Laryngeal muscle activity, subglottal air pressure, and the control of pitch in speech, *Haskins Labs.,* status report on speech research, *SR 39/40,* 137–170, 1974.

DICKSON, D. R., Anatomy of the normal velopharyngeal mechanism, *Clin. Plast. Surg., 2,* 235–248, 1975.

DICKSON, D. R., Normal and cleft palate anatomy, *Cleft Pal. J. 9,* 280–293, 1972.

DICKSON, D. R., Embryology of the peripheral speech mechanism, in *The Nervous System,* D. B. Tower, ed., (3) *Human communication and its disorders,* N.Y., Raven Press, 1975.

DICKSON, D. R., GRANT, J. C. B., SICHER, H., DUBRUL, E. L., PALTAN, J., Status of research in cleft palate anatomy and physiology, I, *Cleft Pal. J. 11,* 471–492, 1974.

DICKSON, D. R., GRANT, J. C. B., SICHER, H., DUBRUL, E. L., and PALTAN, J., Status of research in cleft palate anatomy and physiology, II, *Cleft Pal. J. 12,* 131–156, 1975.

DUFFY, M. M., Restoration of orbicularis oris muscle continuity in the repair of bilateral cleft lip, *Br. J. Plast. Surg. 24,* 48–56, 1971.

FELDMAN, A. S., A report of further impedance studies of the acoustic reflex, *J. Speech Hear. Res. 10,* 616–622, 1967.

FISCHER-JORGENSEN, E., and HIROSE, H., A preliminary electromyographic study of labial and laryngeal muscles in Danish stop consonant production, *Haskins Labs,* status report on speech research, *SR-39/40,* 231–259, 1974.

FLETCHER, S. G., DALY, D. A., Sublingual dimensions, *Arch. Otol. 99,* 292–296, 1974.

FLOWERS, C. R., MORRIS, H. L., Oral-pharyngeal movements during swallowing and speech, *Cleft Pal. J. 10,* 181–191, 1973.

GAY, T., USHIJIMA, T., HIROSE, H., and COOPER, F. S., Effect of speaking rate on labial consonant-vowel articulation, *J. Phon. 2,* 47–63, 1974.

GAY, T., HIROSE, H., STROME, M., SAWASHIMA, M., Electromyography of the intrinsic laryngeal muscles during phonation, *Ann. Otol. Rhinol. Laryng. 81,* 1–9, 1972.

GERWAT, J., The structure and function of the nasopharyngeal lymphoid tissue with special reference to the aetiology of secretory otitis, *J. Laryngol. Otol. 89,* 169–174, 1975.

GLASSCOCK, M. E., Pediatric Otology, *J. Tenn. Med. Assn. 64,* 19–28, 1971.

GREISEN, O., NEERGAARD, E. B., Middle ear reflex activity in the startle reaction, *Arch. Otol. 101,* 348–353, 1975.

HAMLET, S. L., Vocal compensation: an ultrasonic study of vocal fold vibration in normal and nasal vowels, *Cleft Pal. J., 10,* 267–285, 1973.

HIROSE, H., GAY, T., The activity of the intrinsic laryngeal muscles in voicing control, *Phonetica 25,* 140–164, 1972.

HIROSE, H., GAY, T., Laryngeal control in vocal attack, *Folia Phon. 25,* 203–213, 1973.

HIROSE H., LEE, C. U., And USHIJIMA, T., Laryngeal control in Korean stop production, *J. Phonetics 2,* 145–150, 1974.

HIROSE, H., and USHIYIMA, T., The function of the posterior cricoarytenoid in speech articulation, *Haskins Labs.* status report on speech research, *SR-37/38,* 99–107, 1974.

KAHANE, J. C., The developmental anatomy of the human prepubertal and pubertal larynx, unpublished Ph.D. thesis, U. of Pittsburgh, 1975.

KEITH, R. W., Middle ear function in neonates, *Arch. Otol. 101,* 376–379, 1975.

KENT, R. D., CARNEY, P. J., and SEVEREID, L. R., Velar movement and timing: evaluation of a model for binary control, *J. Speech Hear. Res. 17,* 470–488, 1974.

KEWLEY-PORT, D., An experimental evaluation of the EMG data processing system: time constant choice for digital integration, *Haskins Labs.* status report on speech research, *SR-37/38,* 65–72, 1974.

KLOCKHOFF, I., ANDERSON, H., Reflex activity of the tensor tympani muscle recorded in man, *Acta Otol. 51,* 184–188, 1959.

KOCH, H., On the function of middle ear and eustachian tube, *Acta Otol. Suppl.* 182, 1973.

KRATZ, R. C., The identification and protection of the laryngeal motor nerves during thyroid and laryngeal surgery, a new technique, *Laryngoscope 83,* 59–78, 1973.

KUEHN, D. P., DOLAN, K. D., A tomographic technique of assessing lateral pharyngeal wall displacement, *Cleft Pal. J., 12,* 200–209, 1975.

KUEHN, D. P., A cineradiographic investigation of velar movement variables among normals. Paper presented at the 33rd Annual Meeting of the American Cleft Palate Assn., New Orleans, La., 1975.

KUEHN, D. P., A cineradiographic investigation of velar movement variables in two normals, *Cleft Pal. J., 13,* 88–103, 1976.

LANGDON, H., Morphologic study of the uvulus muscle in the fifteen-week human fetus. Paper presented at the annual convention of the American Cleft Palate Association, May 12, 1976, San Francisco.

LATHAM, R. A., SMILEY, G. R., and GREGG, J. M., The problem of tissue deficiency in cleft palate: an experiment in mobilizing the palatine bones of cleft dogs, *Brit. J. Plast. Surg., 26,* 252–260, 1973.

LEE, F., Orbicularis oris muscle in double harelip, *Arch. Surg., 53,* 409–413, 1946.

LIM, D. J., Functional morphology of the lining membrane of the middle ear and eustachian tube, *Ann. Otol. Rhinol. Laryngol., 83,* 5–34, 1973.

LOWRY, L. D., BILLINGS, B. L., and LEONARD, J. E., Otolaryngic findings in a cleft palate population, *Cleft Pal. J., 11,* 62–65, 1974.

MALANNINO, N., Laryngeal neuromuscular spindles and their possible function, *Folia Phoniat, 26,* 291–292, 1974.

MATSUYA, T., MIYAZAKI, T., and YAMAOKA, M., Fiberscopic examination of velopharyngeal closure in normal individuals, *Cleft Pal. J., 11,* 286–291, 1974.

MAUE-DICKSON, W., DICKSON, D. R., and ROOD, S. R., Anatomy of the eustachian tube and related structures in age-matched human fetuses with and without cleft palate, *Trans. Am. Acad. Ophthal. & Otolaryng., 82,* 159–163, 1976.

MCWILLIAMS, B. J., LAVORATO, A. S., and BLUESTONE, C. D., Vocal cord abnormalities in children with velopharyngeal valving problems, *Laryngoscope, 83,* 1745–1753, 1973.

MINIFIE, F. D., ABBS, J. H., TARLOW, A., and KWATERSKI, M., EMG activity within the pharynx during speech production, *J. Speech Hear. Res., 17,* 497–504, 1974.

MISURYA, V. K., Functional anatomy of tensor palati and levator palati muscles, *Arch., Otolaryngol., 102,* 265–270, 1976.

MIYAWAKI, K., HIROSE, H., USHIJIMA, T., and SAWASHIMA, M., A preliminary report of the electromyographic study of the activity of lingual muscles, *Ann. Bull. RILP, No. 9,* 91–106, 1975.

MIYAZAKI, T., MATSUYA, T., and YAMAOKA, M., Fiberscopic methods for assessment of velopharyngeal closure during various activities, *Cleft Pal. J., 12,* 107–114, 1975.

MOLLER, A. R., Bilateral contraction of the tympanic muscles in man. Examined by measuring acoustic impedance-change, *Ann. Otol., 70,* 735–752, 1961.

NISHIO, J., MATSUYA, T., MACHIDA, J., and MIYAZAKI, T., The motor nerve supply of the velopharyngeal muscles, *Cleft Pal. J., 13,* 20–30, 1976.

NISHIO, J., MATSUYA, T., IBUKI, K., and MIYAZAKI, T., Roles of the facial, glossopharyngeal and vagus nerves in velopharyngeal movement, *Cleft Pal. J., 13,* 201–214, 1976.

PEARSON, B. E., Laryngeal microcirculation and pathways of cancer spread, *Laryngoscope, 85,* 700–713, 1975.

PETERSON, S. J., Velopharyngeal function: some important differences, *J. Speech Hear. Res., 38,* 89–97, 1973.

RAMASWAMY, S., and KULASEKARAN, D., The ganglion on the internal laryngeal nerve, *Arch. Otolaryngol, 100,* 28–31, 1974.

RAPHAEL, L. J., The physiological control of durational differences between vowels preceding voiced and voiceless consonants in English, Haskins Laboratories: Status Report on Speech Research, *SR-39/40,* 199–211, 1974.

REES, T. C., SWINYARD, C. A., and MARQUIS, J., The prolabium in the bilateral cleft lip, *Plast. Reconst. Surg., 30,* 651–661, 1962.

RICH, A. R., The innervation of the tensor veli palatini and levator veli palatini muscles, *Johns Hopkins Hospital. Bull., 355,* 305–310, 1920.

RICH, A. R., A physiological study of the eustachian tube and its related muscles, *Johns Hopkins Hosp. Bull., 352,* 206–214, 1920.

RYAN, W. J., and HAWKINS, C. F., Ultrasonic measurement of lateral pharyngeal wall movement at the velopharyngeal port, *Cleft Pal. J., 13,* 156–164, 1976.

SHELTON, R. L., and TRIER, W. C., Issues involved in the evaluation of velopharyngeal closure, *Cleft Pal. J., 13,* 127–137, 1976.

SHPRINTZEN, R. J., LENCIONE, R. M., MCCALL, G. N., and SKOLNIK, M. L., A three dimensional cinefluoroscopic analysis of velopharyngeal closure during speech and nonspeech activities in normals, *Cleft Pal. J., 11,* 412–428, 1974.

SHPRINTZEN, R. J., MCCALL, G. N., SKOLNICK, M. L., and LENCIONE, R. M., Selective movement of the lateral aspects of the pharyngeal walls during velopharyngeal closure for speech, blowing, and whistling in normals, *Cleft Pal. J., 12,* 51–58, 1975.

SIMPSON, R. K., and AUSTIN, A. A., A cephalometric investigation of velar stretch, *Cleft Pal. J., 9,* 341–351, 1972.

SKOLNICK, M. L., and MCCALL, G. N., Velopharyngeal competence and incompetence following pharyngeal flap surgery: video-fluoroscopic study in multiple projections, *Cleft Pal. J., 9,* 1–12, 1972.

SKOLNICK, M. L., MCCALL, G. N., and BARNES, M., The spincteric mechanism of velopharyngeal closure, *Cleft Pal. J., 10,* 286–305, 1973.

SOLOMON, G., and STARR, A., Electromyography of middle ear muscles in man during motor activities, *Acta. Neurol., 39,* 161–168, 1963.

SOAMES, J. V., A review of the histology of the tongue in the region of the foramen cecum, *Oral Surg., 36,* 220–224, 1973.

TANABE, M., KITAJIMA, K., and GOULD, W. J., Laryngeal phonatory reflex. The effect of anesthetization of the internal branch of the superior laryngeal nerve: Acoustic aspects, *Ann. Otol. Rhinol. Laryngol., 84,* 206–212, 1975.

TOO-CHUNG, M. A., and GREEN, J. R., The rate of growth of the cricoid cartilage, *J. Laryngol. Otol., 87,* 65–70, 1973.

TUCKER, J. A., and TUCKER, G. F., Some aspects of fetal laryngeal development, *Ann. Otol., 84,* 49–55, 1975.

USHIJIMA, T., and HIROSE, H., Electromyographic study of the velum during speech, *J. Phonetics 2,* 315–326, 1974.

USHIJIMA, T., and HIROSE, H., Electromyographic study of the velum during speech. Haskins Laboratories: Status Report on Speech Research, *SR-37/38,* 79–95, 1974.

WYKE, B., Laryngeal myotatic reflexes and phonation, *Folia Phoniat, 26,* 249–264, 1974.

ZAGZEBSKI, J. A., Ultrasonic measurement of lateral pharyngeal wall motion at two levels in the vocal tract, *J. Speech Hear. Res., 18,* 308–318, 1975.

ZWITMAN, D. H., GYEPES, M. Y., and WARD, P. H., Assessment of velar and lateral wall movement by oral telescope and radiographic examination in patients with velopharyngeal inadequacy and in normal subjects, *J. Speech Hear. Dis., 41* (3), 381–389, 1976.