Paparella: Volume I: Basic Sciences and Related Principles

Section 2: Physiology

Part 2: Head and Neck

Chapter 15: Physiology of the Mouth, Pharynx, and Esophagus

Physiology of the Mouth

James F. Bosma

The mouth has several functions, most of which are shared with the pharynx. Unlike other sensory and motor parts of the body, such as the limbs, the mouth and the pharynx are continuously active during periods of sleep and wakefulness, both as a sensory source and in sensorimotor performance. During sleep, the mouth is actively held in stable position, except for non-nutritional sucking in infancy and instances of molar grinding (bruxism) in children or adults. Animal studies demonstrate that trigeminal motor neuron activity, as indicated by the pattern of the masseteric reflex, varies with the level of natural sleep in correlation with variations in the patterns of eye movement (Nakamura and Goldberg, 1978).

In the awake state, the mouth and pharynx actively participate in maintaining the posture of the neck as well as the position of the structures about the pharyngeal airway. The oral area is also engaged in a variety of minor gestures that reflect both established habit patterns and the current degree of attention and other social or subjective circumstances. The gestures are also appropriate to the current status of development, whether of infancy, childhood, adulthood, or the aged. These minor gestures are related in pattern to the major performance categories of *alimentation, respiration,* and *position.*

Alimentary, Respiratory, and Positional Functions of the Mouth

The mouth and pharynx perform together in the alimentary functions of feeding and emesis and in the respiratory functions of crying, speech, and coughing. The mouth participates with the pharynx in rumination, which in humans is an incidental alimentary function, and in yawning, an incidental respiratory function.

In this chapter, positional function is considered a major category of oral and pharyngeal performance, along with alimentary and respiratory performances. Motor stabilization of oral and pharyngeal position is continued during quiet tidal respiration; this positioning about the pharynx is the basic mechanism of maintaining the pharyngeal airway during nasal portal respiration. The positioning of the mouth and pharynx is the reference, or background, coordination of feeding and of crying or speech. The positional mechanisms of the mouth and pharynx are integrated with the postural mechanisms of the head and neck. By this integration, the neck and upper trunk are involved in the performances of feeding and speech. The performance mechanisms of positional stabilization evolve separately during neurologic development and are liable to separate forms of distortion in central nervous system impairment.

A distinct positional achievement during development is that of formation of the oral chamber. When the mouth of the normal infant at term is not participating in feeding or respiratory maneuvers, the oral chamber is closed by active approximation of the tongue to the length of the palate. The pharyngeal portion of the tongue approximates the pharyngeal, or muscular, portion of the palate. The oral portion of the tongue approximates the oral palate. The upper and lower lips are in apposition, and the tongue tip participates in labial closure when it is not pressed against the palate. Thus, the oral chamber is potential, except during crying or nipple sucking. At all postnatal stages, the central oral, or lingual, cavity is separated from the pharyngeal airway by apposition between the pharyngeal palate and the tongue. Following childhood enlargement of the oral chamber and dental eruption, a new pattern of stable closure of the labial orifice develops, ie apposition between the mucosae becomes closer to the mucocutaneous junction of each lip. The lips are in continuous approximation to the teeth; the labial and buccal cavities are opened only during feeding and in certain exceptional performances such as playing wind instruments or in buccal speech. Some persons habitually retain a mass, such as food or tobacco or favorite object, in the buccal cavity.

The oral chamber is the central theater of the salivary system (Fox et al, 1085). Saliva is elicited principally from the mouth and is also the mouth's ambient medium, supplemented by food at mealtimes. Saliva is the physical and chemical substrate for oral sensation, particularly of taste. The saliva secrete during and in anticipation of feeding contains a digestive enzyme, amylase, capable of splitting complex carbohydrates into tastable sugars. Saliva is also the medium of diffusion within the oral chamber of such antimicrobial factors as the individual may be able to generate.

The mouth is more than an implement of ingestion. Oral stimulation arouses appetite; in the rat, taste interacts with hunger that is elicited by electrical hypothalamic stimulation (Coons and White, 1977). Over the extended developmental timetable, taste and other oral components of feeding aid in forming dietary preferences and feeding patterns (Davis, 1939; Weiffenback, 1977; Rozin, 1977). The oral experience pertinent to feeding is supplemented by olfaction, although humans, like other primates, are microsmatic (see review by Mugford, 1977). Dietary preferences and feeding patterns subsequent to the suckling period of infancy are much influenced by family and community mores. As the result of changes in agriculture, in the industrialization of food preparation, and in marketing, the composition of the diet of much of the population of the Western world has changed radically, with a differential increase in sugar and fat content. This is a matter of concern at the national level (Select Committee on Nutrition and Human Needs, 1977).

The feeding performance facilitates alimentary functions by stimulation of peristalsis and by elicitation of pancreatic and other alimentary exocrine secretions (Pavlov, 1910; Presham et al, 1966; Epstein, 1976). During the preabsorptive interval, the feeding performance also directly evokes centrally regulated metabolic effects that are essentially identical with those resulting from absorption from the gut (Nicolaidis, 1977). Reciprocally, animals maintained by infusions into the gut inefficiently utilize the infused food (Nicolaidis, 1977). Similar facilitatory effects of oral stimulation, particularly of taste, are noted in humans (Nicolaidis, 1977). In gastrostoma-fed human volunteers, oral food experience contributes importantly to feeding satisfaction and satiety (Jordan, 1969).

In a larger perspective, the mouth, whether at rest or during feeding or in other performances, is a sensory resource that contributes continuously to the sensory flow by which the organism is maintained. The sensory input is generated by motion, activating a sensory resource that develops early and is remarkably rich and heterogenous in its network of mucosal receptors. This internally generated sensory resource is apparently of greater significance during infancy. The infant is more extensively and fundamentally orally oriented than is the person later in development.

Sensory input is a key element in the development of oral performances. Developmental generation of the central nervous system representation of performances of the mouth and pharynx, like those of sensorimotor development in general, depends on sensory input. Sensory inputs from the acting structures are essential for the perfection of competence. Much of sensorimotor development can be defined by the maturation of the peripheral sensory receptors and primary nuclei and of the central nervous system representations of particular functions. Maturational changes in feeding, speech articulation, and positional performance reflect changes (1) in the local sensorium; (2) in other senses, such as hearing, which are less directly pertinent to the action; and (3) in the level of representation of the functions. Controls of postnatal oral performances are accumulated in the brain as a succession of maturational processes within each of the categories of oral function. At the highest level of developmental encephalization, volition is progressively imposed upon the oral performances, relating them not only to oral perceptual information but to all the sensory resources and accumulated experience of the individual. Each of the successive coordination patterns is appropriate to the current peripheral effector anatomy of the muscles, fasciae, skeleton and teeth. In this matching of motor coordination and effector anatomy, the motor performances determine the developmental structure and form of the muscles, fasciae, and skeleton.

The development and eruption of the teeth are separate and distinct from the performance-responsive development of the rest of the mouth. The teeth reflect specific genetic determinants of their number, shape, and dimension. This difference in development mechanisms may be reflected in some of the dimensional discrepancies between the dental and the extradental portions of the mouth.

An individually unique composite of oral performances and oral effector anatomy is generated by these developmental mechanisms. The individuality of the oral area is an important consideration in the examination and treatment of the mouth at any age. A person's mouth, in performance and in anatomy, is the product of that person's unique developmental experience. The range of normalcy is thereby expanded.

The Mouth of the Infant

The mouth of the infant at gestational term is that of a typical newborn mammal in anatomy and function (Figs. 1 to 4). The positional arrangement of the oral structures, in intervals between suckle feeding and crying, is that of a closed chamber. The tongue is held in stable apposition to the oral, or bony, palate; the upper lip and the lower lip are similarly apposed. In premature infants, this pattern of positioning is acquired in an anteriad sequence. In the small premature infant of 7 months gestation, the junction of the mouth and pharynx is closed during nasal respiration, by apposition of the pharyngeal portion of the tongue with the pharyngeal, or muscular palate. In subsequent weeks of life, the premature infant's mouth is progressively closed when not active in feeding or crying, as the oral portion of the tongue is apposed to the oral palate and, finally, the lips are in apposition. This oral apposition is integral to the positional mechanisms of the pharyngeal area, by which the pharyngeal airway is maintained (see later section on Physiology of the Pharynx).

Suckle Feeding

Suckle feeding is a sensorimotor performance that is mature at gestational term. It becomes fully competent within 2 hours of birth of a normal infant (Anderson, 1977). Suckling is an infant's principle behavior during the first post-term weeks. The recurrent process of feeding is a major factor in establishing and maintaining periodicity of arousal; reciprocally, the arousal readies the infant for feeding. The feeding impetus of the newborn, which is analogous to hunger, is less clearly related to nutritional privation in infants than it is in children or adults.

The neurophysiology of suckle-feeding performance has been well studied in infant cats by Anokhin and Shuleikina (1977). The suckle-feeding action is regulated in the reticular formation of the medulla and pons. The important role of the oral mucosal sensation in modulating general activity, as well as in guiding the suck, is indicated by the effects of topical oral anesthesia in newborn kittens. The kittens engaged in frantic and continuous nipple searching but were unable to grasp and retain the nipple when they happened upon it.

Neuropharmacologic studies in infant rats show that the central nervous system regulation of infant suckling is controlled by a specific neurotransmitter system involving serotonin inhibition (Nock et al, 1978).

The mere performance of suckling is satisfying to the young infant, aside from the satisfaction derived from nutritional intake. Thus, a breast-fed infant may be nutritionally deprived without becoming restless or crying excessively (Davies and Evans, 1977; Evans and Davies, 1978).

The head gestures of transverse and vertical nipple approximation, or rooting, can usually be elicited by touching the face of a feeding-ready infant. The lips part and the jaws open to receive and enclose the nipple by a latching gesture. Intraoral stimulation by insertion of a nipple or similar object usually elicits sucking in a feeding-ready infant. In rats, olfaction is essential for the elicitation of sucking (Blass et al, 1977). However, it has not been shown to be a factor in initiating the feeding impetus in human infants; some infants who lack olfaction do suckle-feed in normal manner.

Sucking is accomplished by motions of the tongue, lower lip, and lower jaw in relation to the palate, upper jaw, and upper lip. The moving composite is designated the motor implement of sucking. Its motions form a pattern of repetitive, reciprocal coordinations: (1) the nipple is compressed by elevation of the tongue and lower jaw, and (2) negative pressure is developed in the primary bolus accumulation area posterior to the nipple by a downward and forward motion of the tongue and jaw (Fig. 5). These reciprocating coordinations of sucking are very similar in pattern and temporal relation to those of licking in lower mammals, in which this rhythmic reciprocity is attributed to an oscillatory mechanism in the area of the hypoglossal nuclei (Wiesenfeld et al, 1976).

The motor patterns of suckle feeding, like those of oral positional maintenance, are acquired in an anteriad sequence. This sequence can be observed in the development of infants born prematurely. The small premature infant is competent in swallowing but capable of only occasional sucking. As the infant matures, sucking becomes stronger and more rhythmic, and, finally, the gestures of latching and of rooting are acquired. By inference, this evolution of performance probably reflects the related developments of the mucosal sensory receptors and the representation of the feeding function in the brain stem and cerebellum. However, the histologic changes in the oral sensory receptors linking these developments have not been defined.

Sucking and swallowing are closely related. Sucking facilitates the elicitation of swallowing. In the infant, swallowing can occasionally be elicited along with sucking by touch stimulation of the margin of the lips or of the tongue. In the mature infant, sucking, swallowing, and the breaths taken between swallows recur in a temporally stable pattern that is characteristic of the individual infant throughout his or her period of suckle feeding (Peiper, 1963; Johnson and Salisbury, 1977).

Non-Nutritional Sucking

Sucking without an object in the mouth, which is designated "empty sucking" by Peiper (1963) or "non-nutritional sucking" by Wenner and associates (1970), is common in infancy. It occurs in bursts during sleep, and indicates periodic thalamic activation (Denenberg, 1977). Non-nutritional sucking with an object in the mouth may reflect detection of change in an external stimulus. Within the first few weeks of life, an infant can "learn" to evoke and sustain a projected trigger (Siqueland and DeLucia, 1969; Butterfield and Siiperstein, 1972).

Infant Crying, Coughing, and Emesis

In infant crying, the oral actions are also coordinated with those of the pharynx (Fig. 6). During the phonated expiration, the mouth opens by downward and forward displacement of the jaw; the tongue tip is commonly protruded forward and upward, and the body of the tongue is median grooved (Bosma et al, 1966a). These general performances of the mouth, pharynx, and larynx are keyed with the reciprocal coordinations of effortful expiration and inspiration. During the inspirations between cries, the tongue becomes partially flattened and rises toward the palate; the inspirations are partially through the nose. External observations shows that the oral gestures of coughing are similar to those of crying. In addition, the gestures of emesis are grossly similar to those of crying expirations.

Postinfantile Maturation of the Mouth

During postnatal development, the human mouth evolves from the sucking organ typical of mammalian infants into the most elegantly specialized sensorimotor implement of the human species. Its developmental evolution is derived from a system in apposition, essentially evolving from a pump with a small chamber to an open chamber, with the tongue being a freely mobile implement within it. This evolution is cued and guided by related developments of the oral sensorium and of connections of the sensorium to representations of oral and pharyngeal performances in the central nervous system. With developmental encephalization, the mouth becomes a major sensory resource of conscious subjective experience. The sensory inputs from the oral area developmentally influence not only the maturation of their immediate representations in the brain stem and cerebellum but also their derived representations in the cerebellum. When not engaged in specific voluntary performances, the oral area is perceptually silent and subjectively neglected. During most of its voluntary actions, the mouth performs in relation to the collective effect of the input of its several modalities of mucosal sensibilities. But the sense of taste remains discriminate and may be perceived in one or a combination of its four basic modalities (salty, sweet, tasteless, sour or bitter). In infants and young children, chemosensation of sucrose or of a salty solution may directly elicit the reflexive transverse motor responses in the tongue in a manner that is apparently identical to the elicitation of these responses by touch (Weiffenback, 1972; Weiffenbach and Thach, 1973; Thach and Weiffenback, 1976). This response system is lost during childhood: Chemosensory elicitation of lingual motor response is not recognized in children or adults.

The oral cavity is differentially enlarged about the tongue, similar to differential enlargement of the upper pharynx about the soft palate and of the chamber of the larynx about the arytenoid apparatus. In a remarkable teleologic coincidence involving the tongue, soft palate, and arytenoid apparatus, each becomes more mobile within its respective expanding chamber. This development of chambers and mobilities is, of course, pertinent to human speech (Bosma, 1975). However, these anatomic changes are not generated by the speech performance; much of the speech performance repertoire of the older infant and the preschool child is achieved while the mouth and pharynx are still of infantile proportions (Bosma, 1975). That this anatomic change is related to sensorimotor maturations in the oral and pharyngeal areas is indicated by clinical syndromes of oral and pharyngeal sensory deficiency. In these disorders, the mouth and pharynx retain infantile performance patterns and grow in infantile proportions (Bosma et al, 1967).

Growth and eruption of the teeth (Scott and Symons, 1961; Sicher and Bhasker, 1972) and the associated adaptations in form, size, and structure of the dental skeleton reflect general somatic instigations of development. Pertaining to feeding and to erect posture, the mandible enlarges disproportionately to the maxilla, becoming relatively prognathic. The angle of the incisor teeth becomes more vertical (Björk, 1953). The contour of the incisors is correlated with patterns of activity in the upper lip muscles (Ingervall, 1976). The mandible is mechanically stabilized by the glenoid fossa, which is formed during postnatal development. The teeth, dental skeleton, and related adaptations of the jaw muscles and their fasciae constitute the motor implements of mature feeding. The teeth are a highly significant sensory resource in biting and chewing, which involve interdental contact either directly or with food interposed. The teeth and jaws have a less definite role in positional performance and in speech and other mobile nonfeeding performances. The position of the teeth in the maturing form of the mouth is more relevant to positional function than to biting and chewing.

Postinfantile changes in oral performances follow a pattern of successive maturations. Normally, position maintenance, feeding, and speech articulation progress together in a fairly predictable timetable. However, development in each of these different primary categories of performance may proceed independently in neurologically impaired individuals. Such autonomy of development indicates that these performance categories are separate and, at least potentially, independent in their central representation.

Postinfantile Performances of the Mouth

Feeding

Suckle feeding is replaced by the voluntary, more varied, and more discriminate actions of biting, chewing, and preparation of the swallow bolus. The integrated performances of the tongue, lower lip, and mandible, which constitute the infant's motor implement of suckling, develop into separate performances of each of these three components. Mature oral feeding actions are acquired in sequence: incisor biting, combined with lip and tongue tip manipulation, is followed by molar mastication, combined with cheek and tongue body manipulation. Biting and chewing utilize separate sensory resources and separate motor coordinations of the mandible. Studies employing electromyography, displacement recordings, dynamometry, and measures of chewing efficiency, or trituration, of solids have contributed to understanding of feeding motions (Anderson, 1968; Kapur and Collister, 1970; Klineberg and Wyke, 1972; Kawamura, 1974; Møller, 1974). The central representations of biting and chewing extend through the brain stem and cerebellum to the precentral cerebral cortex (Kawamura, 1974; Miller and Bowman, 1977).

The selection of the swallow bolus from oral contents and the sizing of the bolus in the swallow preparatory area are separate maneuvers. The initiation of swallowing is voluntary, and the pattern of its initial motions is varied. The bolus may be delivered into the pharynx in close containment between the tongue and soft palate, with swallow ensuing immediately. Or the bolus may be spilled into the pharynx, with swallow ensuing after a variable interval.

Development of these mature mechanisms of feeding reflects maturation of the mucosal sensorium and of the central representations of the feeding performance. During this maturation, the mouth and pharynx change in form and spatial arrangement; the tongue and hyoid descend in relation to the midfacial skeleton, and the meso- and hypopharynx are elongated. In addition, the oral feeding and swallowing motions of the tongue become principally vertical in orientation. The schedule of transition from infantile oral performance patterns varies among children. In some children, the descent of the hyoid and tongue, in relation to the facial skeleton, and the coincident expansion of the oral chamber about the mass of the tongue are delayed. This may be a factor in a disproportionate forward motion of the hyoid and tongue during swallowing and certain speech maneuvers. In children who exhibit "tongue-thrusting", the tongue protrudes between the incisor teeth during these performances. In some of the children who thus have delayed development of oral coordination, the tongue tip at rest may be in sustained apposition with the lower lip. In children who manifest the tongue-thrusting pattern of oral coordination, the upper and lower incisor teeth may be displaced from their normal approximation, in an "open bite" pattern. The majority of tongue-thrusting children develop normal adult oral and pharyngeal motor patterns and corresponding oral and pharyngeal anatomic arrangements (Fletcher, 1975). This transition "is characterized by an increased elevation of the tongue tip and sides as the jaws are brought together and the tongue is contained within the dentition" (Lowe, 1981). A variety of empirical exercise routines are said to facilitate this aspect of development.

The coordinated oral and pharyngeal performance of suckle feeding is retained into neurological maturity, although its corollary reflexes of rooting and nipple latching are lost. The continuation of breast-feeding after mature feeding performance is acquired varies with local traditions, customs, and nutritional needs. Prolonged breast-feeding extends the attachment bonds of mother and infant and also provides nutritional support for the infant or young child, which may be critical during periods of famine (Jelliffe and Jelliffe, 1977; Knodel, 1977). If the nutrition of the mother is marginal, prolonged lactation delays the return of ovulation and thus diminishes the chance of pregnancy (Knodel, 1977). Prolonged breast-feeding has been indicated as a cause of dental caries (Kotlow, 1977); however, this concept has been effectively challenged by Countryman (1978). Prolonged bottle-feeding has been more clearly identified as a cause of dental caries, particularly if a sweetened formula is fed and if the bottle-feeding is intermittent during the sleeping period (Gardner et al, 1977). Candy pacifiers have a similar cariogenic effect; these pacifiers are now prohibited from being sold in the United States.

Positional Performance

As a result of the differential enlargement of the oral cavity about the tongue and the separation of the tongue (in resting position) from its infantile diffuse apposition to the oral palate and upper jaw, the mechanism of position maintenance are necessarily changed. The mandible acquires a greater position-stabilizing role with reference to the mouth, the pharyngeal airway, and, more generally, the head and neck. The mandible is enlarged and is stabilized by the glenoid fossa of the temporomandibular joint. Proprioception in the mandibular joint and the mandibular muscles probably increases. Dental sensibilities play little part in this positional role of the mandible; the teeth are seldom in approximation except during feeding, rumination, or gross struggle. The neuromuscular mechanisms involved in mandibular posture have been extensively studied, particularly in regard to dental extractions and to symptoms of pain about the temporomandibular articulation (Wyke, 1974; Møller, 1974; Tallgren, 1957). Inputs from the temporomandibular joint contribute significantly to the regional sensory resources that control tongue motions (Lowe, 1981).

The positional mechanisms of the tongue are of importance in pharyngeal participation in respiration, including the maintenance of the pharyngeal airway. The genioglossus muscle, in particular, is consistently active during inspiration.

During childhood, the mouth matures as a secretory and manipulative chamber. As in the infant, the junction of the mouth and pharynx continues to be closed by stable apposition between the pharyngeal, or muscular, palate and the junction of the oral and pharyngeal portions of the tongue. Most of the pharyngeal aspect of the tongue faces on the pharynx when the hyoid has descended in relation to the facial skeleton. Stable closure at the front of the mouth by apposition between the lips is a separate maturational process. Labial spill occurs freely in young infants and becomes conspicuous when the infant achieves upright posture. This continues until the labial gate matures into stable apposition. In some individuals at rest, lip closure is supplemented by apposition of the tongue tip to the maxillary upper incisors. The oral chamber thus may stably retain food and saliva.

Salivation

The baseline secretion of saliva maintains the oral mucosae in a normal state (Mandel and Wotman, 1976). Salivary secretions and taste and other oral sensations are closely correlated. The secretions are increased reflexively by oral taste or mechanical stimulation, as well as by psychic stimuli such as the sight or smell of food or by sexual stimuli. Reciprocally, saliva influences taste; a specific taste-facilitating salivary constituent has been suggested (Henkin, 1977). The salivary electrolytes also determine the taste perception of electrolytes in exogenous solutions delivered to the mouth. A solution of sodium chloride is perceived as "salty", "sweet", "tasteless", or "bitter-sour" as its concentration is decreased from well above to well below that of saliva (Bartoshuk, 1974, 1977). Most of the secretions are passed to the pharynx during feeding or by incidental diffusion. The oral, nasal and pharyngeal secretions occasionally are collected and elicit swallowing. Saliva moistens the lips. In addition, a small portion is spread into the environment by labial spill, by droplets during speech, or by spitting.

Speech

Human speech is distinguished from vocal expressions of other primates by its oral articulation. Speech articulation specifically utilizes the combination of an expanded oral chamber and a discriminately mobile tongue, lips, and jaw, which humans acquire during postnatal development. Analogous oral gestures are involved in singing and in playing musical wind instruments. The composites of articulation approximations and chamber contouring vary according to the individual's pattern and extent of development as well as the language context.

The acoustical products of each of the articulation performances are far more uniform in their essential perceptual components than are the peripheral motor implements by which different individuals articulate speech. Accordingly, the speech performance adaptations to oral anatomic variations vary extensively. Both hearing and local oral and pharyngeal tactile and kinesthetic sensations have a role in guiding these adaptations during prespeech gesturing, in early speech, and in mature speech performances (McDonald, 1964; Fucci et al, 1977). Speech articulation is markedly impaired in some children having primary impairments of oral sensation and perception (Bosma et al, 1967). It is reasonable to presume that the motor refinements of speech articulation are the product of sensorimotor mechanisms analogous to those employed in oral feeding and in fine coordinations elsewhere in the body, as in the hand. But the effectors of speech are more heterogenous, are anatomically more dispersed, and perform in a greater variety of patterns and schedules and with greater relevance to the environmental circumstance and/or context than is true of any other sensorimotor coordination. Speech is, clearly, the ultimate externalized performance of humans.

Other Functions and Performances of the Mouth

The mouth is the site of a considerable array of repetitive stereotypic performances that characteristically have a prominent sensory component and apparently contribute subjective satisfaction. Such performances commonly indicate tensional states and frequently are manifested just prior to or during sleep. These are typically extensions in pattern from the basic oral performances, particularly of feeding. In this category are lip sucking, cheek sucking, tongue sucking, and molar grinding (bruxism). The rhythmic schedule of sucking activity may extend to motions of the head or hand. Lip, cheek, and tongue sucking are inconstantly associated with the persistence of the infantile pattern of forward motion of the tongue and hyoid during swallowing. The repetitive sucking is not, of course, the cause of the tongue thrusting. The infantile or early childhood antecedents of bruxism are not recognized. But bruxism, like the sucking of mouth parts, has been resistant to therapy by suggestion, hypnosis, or biofeedback training (Glaros and Rao, 1977). However, Kardachi and Clarke (1977) reported improvement in bruxism during sleep by use of a biofeedback technique. An audible tone reflecting electrical activity in the masseter or temporalis muscle caused significant reduction in bruxism, and the reduction was tentatively attributed to alteration in the level of sleep. A variety of dental measures, including occlusal adjustment and bite plates, have also been employed in therapy (Schärer, 1977).

A remarkable variety of substances and objects are incorporated into habitual oral gestures that deviate from ordinary feeding gestures. Bottle-feeding or the use of infant pacifiers may be inordinately prolonged. as previously mentioned, continued bottle-feeding or sucking or candied pacifiers in childhood may be cariogenic. Some children, who are stress-reacting or neurologically impaired, retain a food mass, commonly in the buccal cavity. This may be interspersed with rumination. Compulsive eating of odd ingesta, such as clay or ice, is termed pica. This is statistically associated with iron deficiency. Oral iron therapy results in prompt relief of this aberrant behavior, even before elevation of the hemoglobin level in the associated iron deficiency anemia occurs (Crosby, 1976).

In higher mammals, the mouth is an important sexual resource. It is a major erogenous zone, as its stimulation during sexual contact elicits psychological and endocrine responses. The mouth itself responds to sexual stimulation in other areas by sensitivity, vascularity, and salivation. The adequacy of sexual gestures of kissing, biting, sucking, and licking is an important consideration in therapy of persons with impaired oral anatomy or neurologic performance.

A variety of oral perceptual sensitivities have been distinguished that are as yet incompletely related to the primary oral performances of positioning, hearing, and speech. These include vibrotactile discrimination (Fucci et al, 1977; Telage and Warren, 1977); discrimination of texture, as of grades of paper (Ringel and Fletcher, 1967); interdental thickness discrimination (Williams et al, 1974); and oral form recognition, or stereognosis (Arndt et al, 1970; Johnson et al, 1977). Continuing study of these perceptual competencies will extend their definition and the definition of oral sensory competencies. Oral stereognosis impairment has been grossly correlated with lesser competence of speech articulation (Weinberg et al, 1970; Moser and Houck, 1970). Tongue manipulation of varied forms successively stabilized on an intraoral prosthesis is being employed in trial therapy of oral coordinative impairments (Haberfellner and Rosiwall, 1977). In our current understanding of oral performances, these more complex perceptual competencies remind us of the elegance of oral perception and that oral sensory representation extends to the highest levels of human perceptual abilities.

Physiology of the Pharynx

James F. Bosma, Martin W. Donner

In humans, as in the Mammalia generally, the pharynx is located at the intersection of the foodway and the airway and also at the junction of the neck with the base of the cranium and the face. Physiologically, the pharynx participates in feeding, in rumination and vomiting, and in several patterns of respiratory performance. In addition, incident to maintenance of the pharyngeal airway, the pharynx functions as a central, focal element in the coordination of craniocervical posture.

These performance participations of the pharynx are basically different. The performing pharynx is differentially related in *feeding* to the mouth and the esophagus; in *respiration* to the nose, the larynx, and the lower airway; and in *airway maintenance* to the cervical postural musculature. It is inferred from clinical observations of differential impairment of each of these performance participations that they have different sensory cues from the pharynx and from other structures that participate in the performances. They have different motor expressions, both in their utilization of participating muscles and in their coordination patterns. Finally, they differ in their central nervous system representations. The performances in each category develop on independent schedules. In correlation with changes in performances during postnatal development, the pharynx undergoes extensive anatomic changes, along with the basicranium, the nose, the mouth, and the larynx. In this way, this region achieves its distinctive human form and dimension. These changes are shown schematically. The anatomic arrangement of the structures in the pharyngeal area of the newborn is shown. Postnatally, the facial skeleton enlarges in vertical and anteroposterior diameters. The basicranium and the cervical vertebrae elongate. During childhood and puberty, relatively greater expansion occurs in the upper than in the lower portion of the pharynx. Posteriad enlargement of the upper pharynx is caused by elongation of basisphenoid, and vertical enlargement is effected by downward displacement of the series of skeletal attachments of the pharynx. The medial pterygoid processes and the adjacent nasal skeleton elongate, and thus the pterygoid hamuli and the bony palate descend. The mandibular rami elongate. The hyoid descends in relation to the mandible and to the styloid processes of the temporal bone. Elongation of the superior and inferior thyroid cornua results, respectively, in differential descent of the thyroid alae in relation to the hyoid body and in elongation of the major cartilage portion of the larynx. By the mechanism of skeletal displacement, the pharyngeal palate becomes more mobile. Its "levator" muscles actually become levators, as a result of descent of the oral, or bony, palate in relation to the origin of these muscles. The pharynx elongates in disproportion to the face and the vertebrae so that it descends into the neck. These changes in the pharynx are coincident with enlargement of the chambers of the nose, mouth, and vestibule of the larynx. In a remarkably concomitant development, the contained elements (tongue, pharyngeal palate, and arytenoid apparatus) become more mobile within their respective chambers (Bosma, 1975). The faucial tonsils and the adenoid tissue are transiently enlarged in childhood; the normal pharynx adapts adequately to these lymphoid masses during feeding, airway maintenance, and speech.

These changes in the peripheral performing structures are one part of an integrated developmental composite. The changes directly reflect maturation of the regulation by the brain of the performances of feeding, of participation in respiratory coordinations, and of participation in maintaining regional posture. Maturation of the nervous system regulations is directly dependent on motion-generated sensations from the mucosal sensory receptors and the proprioceptors in muscles and joints of the performing areas. The cycle of influences and reciprocities is thus completed: The maturation of the mouth, pharynx, and larynx and the maturation of the brain pertinent to them are linked by sensory and motor innervations. The integration of the central representations and the peripheral performing parts of the developmental composite is so extensive that developmental retardation of the peripheral apparatus or of the brain representations of its functions may be difficult to discriminate diagnostically. Primary impairments of peripheral structure and form may be associated with impairments of maturation of the central representations of the performances of this region. This is particularly so if the peripheral impairments involve the sensory structures, as in some patterns of malformation (Bosma, 1967). Reciprocally, primary impairments of the central representations of feeding, respiration, and posture in the medulla and pons are reflected in developmental failure and distortion in the peripheral structures.

A critical function is that of the interactions between the regulations of these performances within the medulla and pons. The interaction between swallowing and respiration is the most frequently studied and best defined (Storey, 1976). However, mechanisms of interaction extend between each of the major performance categories of feeding, of rumination and vomiting, of respiration, and of airway maintenance. The patterns of those interactions change with development, along with changes in the performances themselves. In cats, the swallowing/respiration interaction, for example, is more liable to disruption by hypoxia or by pharmacologic agents in the immature than in the mature animal (Sumi, 1975).

Swallowing

The basic physiologic model of pharyngeal swallow, as studied in generally anesthetized or decerebrated animals, is that of elicitation via the superior laryngeal or glossopharyngeal nerves by mucosal or direct nerve stimulation (Doty, 1968; Doty and Bosma, 1956; Bosma, 1957; Storey, 1976; Miller and Loizzi, 1974) or via electrodes in the dorsal reticular formation of the medulla, ventral to the solitary nucleus (Miller, 1972). In such a system, continued stimulation elicits swallowing, which is not fatigued despite prolonged repetition. Each swallow is a stably patterned peristalsis, descending in the constrictors and in the palatopharyngeal, lingual, submental, hyolaryngeal, and laryngeal muscles. As determined by electromyography, this activity is preceded and succeeded by a brief period of inhibition of respiratory or other activity in the individual muscles (Fig. 9). The reflex-elicited swallow progresses through its motor pattern without additional sensory influences (Doty and Bosma, 1956; Miller, 1972).

In humans, swallowing is frequently elicited by secretions from the pharynx, mouth, or nose or from the larynx and tracheobronchial tree. In infants, swallowing is an integral part of the suckle-feeding action (Peiper, 1963). During mature feeding, swallowing is initiated voluntarily, along with delivery of the bolus into the pharynx. In adults, it may be elicited by touch in the mesopharynx (Pommerenke, 1928); topical anesthesia of the pharynx impairs voluntary initiation of swallow Mánsson and Sandberg, 1974, 1975). The swallow, once initiated, progresses without further voluntary control, although voluntary facilitating gestures of the head and neck may be employed in some individuals with dysphagia. The swallowing motions of the pharynx cause an abrupt succession of positive and negative pressures in the nose (Gramiak and Kelley, 1966) and are also associated with an increase in intratruncal pressure. The latter is indicated by an upward propulsion of air or bolus in the esophagus, which may meet the descending swallow bolus in the cervical esophagus.

The opening of the pharyngoesophageal segment (or cricopharynx, per Henderson, 1976; or upper esophageal sphincter, per Ellis et al, 1969 and Ellis, 1971; and others) is effected by the inhibition of the cricopharyngeal muscle, which precedes the swallow activation, combined with upward and forward displacement of the larynx and pressure of the bolus (Doty, 1968; Lund, 1964). A primary peristaltic wave in the esophagus usually follows pharyngeal swallow; if pharyngeal swallows are in rapid succession, the primary esophageal peristalsis is delayed until the conclusion of the series.

The pattern of swallow activation, which is distributed through the lower bulbar and upper cervical motor innervations, and the adjacent inhibition of alternative performances are organized in the medulla. Information about the influences of pharyngeal sensation and of cortical instigation upon this center is reviewed by Doty (1968). The centrally governed coordination differs during postnatal maturation in cats (Sumi, 1975) and in humans (Tulley, 1953).

The pharynx participates in digestion as well as in feeding. During swallowing, a lipase-containing secretion is released into the bolus by the pharyngeal glands of von Ebner, located below the circumvallate papillae at the junction of the pharyngeal and oral portions of the tongue (Hamosh, 1978). These glands are a principal source of alimentary lipase proximal to the pancreas (Salzman-Mann et al, in press). In adults, the lingual orifices of von Ebner's glands are opposite the soft palate, and their secretion is probably released into the bolus during its passage into the pharynx, as well as being released into the pharyngeal secretion pool that accumulates between swallows. In the infant, the tongue is more anterior in relation to the palate (see Figs. 7 and 8) so that the circumvallate papillae approximate the junction of the oral and pharyngeal palate. The primary area for bolus accumulation during infant suckle-feeding is adjacent to the junction of the oral and pharyngeal portions of the palate and to the junction of the oral and pharyngeal portions of the tongue (see previous section, Physiology of the Mouth). By inference, the secretions of von Ebner's glands are released into the bolus that is pooled briefly at this site. The local elicitation of secretory activity of von Ebner's glands is not known; however, its activity is elicitable by food in the stomach (Hamosh and Scow, 1973).

Swallowing and Feeding in Infancy

Isolated pharyngeal swallows that are not related to feeding occur in infants; these are apparently elicited by local stimulation. A swallow commonly occurs after a series of coughs or cries; it is probably elicited by secretions expressed from the tracheobronchial tree, or nose, or both. However, such a swallow, as an alternative performance to coughing or crying, is also a factor in the conclusion of the coughing or crying series.

Suckle feeding is a regional performance of the mouth and pharynx (see previous section, Physiology of the Mouth). The performance is initiated by nipple seeking or rooting, and prehension, or latching. This is followed by an irregular sequence of sucks, swallows and breaths, graduating into the state of established suckle feeding. In this state, the temporal pattern of suckle and swallow and intervening respiration recurs in a stable schedule, the details of which are characteristic of the individual infant (Peiper, 1963; Logan and Bosma, 1967). The elicitation of swallow is facilitated during suckle feeding; accordingly, suckle feeding may be employed to assist swallowing in some neurologic impairments of the pharynx. In infants, the area of swallow that can be elicited by touch is extended to the lip margins and tongue tip; this elicitation is more effective during interruptions of suckle feeding.

A normal pharyngeal swallow by an infant, as demonstrated by cineradiography, is shown. This is in lateral projection with the subject supine and the chin held at 90 degrees to the longitudinal axis of the body. The gate mechanism at the junction of the mouth and pharynx is comparable to that of adults, except that the pharyngeal portion of the tongue extends anteriorly in contact with the posterior margin of the bony palate (see Figs. 7 and 8). The bolus typically is closely contained between the tongue and the pharyngeal palate as it is delivered into the pharynx. The motions of the hyoid bone are principally anteriad. The tongue rotates posteriad in relation to the moving hyoid. The larynx approximates the hyoid and is moved anteriad, though less so than the hyoid. Because the posterior pharyngeal wall moves anteriad, the peristaltic wave on the posterior pharyngeal wall is conspicuous. In the infant, the route of the bolus is displaced further forward in relation to facial and cranial references than in mature adults. The motion pattern of the opening of the pharyngoesophageal segment is similar to that of the mature adult.

The mature pattern of suckle feeding is achieved late in gestation. The small premature infant has adequate isolated pharynx-clearing swallows but acquires suckle and the nipple-seeking maneuvers successively during the premature period.

Much of the evaluation of an infant's swallowing can be accomplished by simple examination procedures. The normalcy of pharyngeal form and mobility can be determined by physical examination of the cervical area, inspection of the oropharynx, and simple "short-tube" endoscopy, supplemented by a standard lateral radiograph employing soft tissue technique. Swallowing can be elicited by delivery of a few milliliters of milk or water into the mouth or via a nasal catheter positioned in the nasopharynx. Since, in a post-term infant, optimal swallow elicitation is achieved during established suckle feeding, suckling should be attempted by nipple feeding of milk or a liquid of equivalent consistency. A useful arrangement is one in which the feeding fluid can be released into the nipple after rhythmic sucking actions have been achieved by oral stimulation.

During suckle feeding in the infant, swallow is integrally related to respiration. Respiration is arrested prior to swallow. Each swallow, or a few rapidly successive swallows, is followed by a "swallow breath".

Adequacy of swallowing can be conveniently assessed by stethoscopic auscultation at the neck; the normal sounds are those of fluid passage and a characteristic double click during the latter part of a swallow. A bubbling sound during respirations, with or without a cough or grunt or respiratory pause, indicates incomplete emptying of the bolus from the pharynx or penetration of the bolus into the larynx. Many infants with pharyngeal dysphagia continue suckle feeding even though laryngeal and tracheal penetration occurs. Marginal competence of swallowing can be evaluated by maneuvers that impede swallowing, such as slight passive extension of the head or neck or gentle finger pressure stabilization of the hyoid and larynx.

These evaluations may be followed, when indicated, by demonstration of the details of the dysphagia by videoradiography or cineradiography. The issues to be addressed by this procedure are few and specific: (1) the competence of control at the junction of the mouth and pharynx, (2) the effectiveness of swallowing in emptying the pharynx, and (3) palatopharyngeal isthmus and/or laryngeal penetration during swallowing. Aspiration of the post-swallow residual bolus into the isthmus or larynx is incidental. The cineradiographic study may demonstrate asymmetry or other local variations of motor function. It may also demonstrate an anomalous or cicatricial web or bar in the pharyngoesophageal segment or a mass intruding into the pharynx. Sufficient information can usually be obtained by radiographic recording in lateral projection of a single swallow or of a suckle and swallow sequence. In some circumstances, a posteroanterior cineradiographic study may also be indicated.

Swallowing in the Child and Adult

With neurologic maturation, the oral components of feeding become voluntary, heterogenous, and extensively adaptive. The mouth becomes competent in discriminating the physical character of the food undergoing oral preparation for swallowing. This perception guides chewing and other oral manipulations of solids. Ordinarily, in humans, large, firm particles in the food mass are chewed and tongue-mashed into a semiliquid consistency prior to accumulation in the swallow-preparatory area on the dorsum of the tongue adjacent to the junction of the hard and soft palates.

The reference for normal swallowing in the child or adult is determined with the subject in upright position, the swallow motion being observed by videoradiography or cineradiography of a barium bolus in lateral or in posteroanterior projection (Fig. 11) (Scatliff and Scibetta, 1963; Donner and Siegel, 1965; Donner and Silbiger, 1966; Seaman, 1973). A barium bolus of 10 to 20 mL is held in the mouth and is kept out of the pharynx by sustained apposition between the soft palate and the pharyngeal portion of the tongue. Swallowing is begun by an upward motion of the tongue lateral and anterior to the bolus, demarcating it from the rest of the oral content; this effectively "sizes" the bolus. The bolus is delivered into the oropharynx by motions of the tongue. The bolus is spilled into the open pharynx or propelled by the tongue by a plunger-like action in relation to the palate and the posterior pharyngeal wall. The pharyngeal palate is displaced upward and backward by the combined action of the levator and palatopharyngeal muscles in order to approximate the posterior pharyngeal wall. The portion of the palate at the insertion of the levator muscles is angled upward into the nasopharynx. The posterior pharyngeal wall in the upper pharynx moves little, but the lateral wall of the epipharynx converges upon the palate (Shprintzen et al, 1975). In some swallows, specifically those associated with suckle feeding (eg when using a straw), the bolus is conveyed into the pharynx fully enclosed between the tongue and palate, and the swallow action proceeds in continuity with the bolus delivery. Alternatively, in normal swallows, an oversized bolus may be released into the pharynx, necessitating a large, gulping swallow, or the bolus may be loosely spilled into the pharynx, and swallow occurs after a variable interval.

As swallowing progresses, the hyoid bone is displaced upward and anteriad. The larynx approximates the hyoid. Elevations of the larynx and the swallow-related motions of the arytenoid apparatus are demonstrable in the radiographic image of the laryngeal conus during lateral radiography. With adduction, the vocal folds become radiographically more distinguishable as a broad band. The vocal chink, or recess, may be briefly distinguishable between the ventricular and vocal folds. The inferior margin of the vocal fold demarcates the laryngeal conus. At its posterior end, the inferior margin of the vocal fold is inconstantly indented upward, adjacent to the arytenoids. During swallowing, the larynx is vertically compressed, as is indicated by elevation of the vocal fold and the arytenoid mass and by radiographic obliteration of the laryngeal vestibule. The larynx as a whole is raised toward the hyoid. Along with these motions of the larynx, the epiglottis is drawn downward at the attachment of the aryepiglottic muscles and, to a variable extent, is pressed posteriad and downward by the tongue. The epiglottis commonly, but not consistently, is tipped into the laryngopharynx, where it is compressed by the descending wave of constriction. Electromyographic studies in experimental animals (Doty and Bosma, 1956) demonstrate that the descending wave is a peristalsis that traverses the skeletal musculature of the entire pharyngeal composite, including the constrictors, and the muscles of the pharyngeal palate, pharyngeal portion of the tongue, and the hyoid and larynx. In mature adults, the motor wave progresses at 12 to 25 cm per second (Atkinson et al, 1957; Kelley, 1964). A phase of inhibition of nonswallowing activity precedes the active peristalsis. The pharyngoesophageal segments is opened by this inhibition of tonus in the cricopharyngeal muscle, ahead of the descending wave of peristalsis; by elevation of the larynx; and by pressure of the descending bolus (Lund, 1964; Seaman, 1966; Doty, 1968; Winans, 1972). The segments is closed at the completion of the swallow by contraction of the cricopharyngeal muscle. The pharynx reopens in a cephalocaudal sequence. A respiration variably follows this sequence of swallowing. The swallow breath occurs less consistently in neurologically mature persons than in suckle-feeding infants.

The pressure phenomena of the swallow performance within the pharyngeal lumen are demonstrable by manometry, employing either intraluminal strain gauges or catheters that are continuously perfused or periodically flushed. More accurate indications of the pressure changes are provided by the intraluminal strain gauges (Dodds et al, 1975). The pharyngeal swallow pressures are recorded from an array of such gauges. The amplitude of the major pressure complex is highest in the laryngopharynx, whereas a pressure trough exists in the oropharynx. Small pressure waves preceding the major pressure complex have been suggested to be caused by swallowing movements of the larynx or tongue (Sokol et al, 1966; Cohen and Wolf, 1968). In normal subjects, the peristalsis amplitude varies between 20 and 60 mm Hg in the laryngopharynx. In contrast, low pressure, between 5 and 10 mm Hg, exists in the oropharynx. The resting cricopharyngeal sphincter pressure, recorded by the pull-through technique, measures 33 ± 12 mm Hg, and the period of sphincter relaxation during swallow measures between 1 and 2 seconds.

Intraluminal pharyngeal manometry provides accurate quantitation of pharyngeal peristaltic variables and serves as the necessary basis for the characterization and assessment of pharyngeal motor disorders. The technique may be particularly useful in combination with cineradiography, and aids in the interpretation of findings of both techniques. More recently, the velocity of the bolus was determined by changes in luminal electrical impedance, recorded by a succession of electrodes, during the passage of a saline bolus through the pharynx

(Fischer et al, 1978). The front face of the bolus that was being ejected from the pharynx into the esophagus ranged in velocity to a maximum of 70 cm per second, in correlation with the volume of the bolus.

Pharyngeal swallow has been observed by multiple input electromyography in coincidence with cineradiography in four normal individuals (Yoshida, 1979). The sequence of swallow activation of the constrictors and the related oral and laryngeal muscles and of inhibition of the cricopharyngeus is similar to the coordination sequence described in experimental animals by Doty and Bosma (1956) and others. Similar studies were performed in pharyngeal dysphagia associated with amyotrophic lateral sclerosis (Ohkubo, 1980), oculopharyngeal muscular dystrophy (Ohkubo et al, 1978), or cerebrovascular disease (Toh, 1982). Hirano and coworkers (1981) specifically observed participation of the cricopharyngeus in the swallow coordination by combined radiographic and electromyographic observations in dysphagic persons who had neuromuscular disorders. They found that cricopharyngeus relaxation occurred in normal temporal relation within the swallow coordination. Exceptional prominence of the cricopharyngeal intrusion into the progressing bolus resulted, in most instances, from impairment of bolus propulsion, resulting from constrictor or lingual weakness. In other dysphagic persons, prominent cricopharyngeal intrusion reflected a decrease in cricopharyngeus elongation secondary to myopathy. This variety of possible mechanisms of intrusion of the cricopharyngeal elongation secondary to myopathy. This variety of possible mechanisms of intrusion of the cricopharyngeal bar into the barium bolus is recognized by Goyal (1984). In an extensive review of the cricopharyngeus, both normal and disordered, Goyal notes that protrusion of the cricopharyngeal bar during swallow (termed cricopharyngeal achalasia) is noted in 5 per cent of apparently normal persons. Dysphagia symptoms or radiographically demonstrated obstruction are poorly correlated with extent of protrusion of the bar, if obstruction is not complete.

The sounds of swallow in an adult are similar to those in infants, but the double click in the area of the hypopharynx is louder. The sounds of bolus passage are more varied, depending upon the physical character of the bolus and the extent of its admixture with air (Logan et al, 1967).

The available physical descriptions of swallow are pertinent to "dry swallows" of oral and pharyngeal secretions, with no added bolus, or to swallows of liquid, such as a barium mixture. Clinical observations indicate that liquid of the consistency of milk causes the least difficulty in most children and adults with pharyngeal dysphagia. In this, they are similar to dysphagic infants. In oral and pharyngeal dysphagias, water is manipulated with difficulty. Carbonated beverages readily penetrate the larynx or palatopharyngeal isthmus if their closure during swallow is inadequate. In some patients with oral dysphagia, semisolids are more easily manipulated into the pharynx. A solid or semisolid component in a bolus evokes greater effort and, we suspect, somewhat different swallowing motions. A useful question in the clinical history of such patients is the size of tablet or capsule that can be swallowed. Acutely critical dysphagia, with pharyngeal or laryngeal obstruction, is caused by solid masses or, rarely, by a paste, such as peanut butter.

Air Swallowing into the Esophagus

Swallowing is involved in moving air as well as secretions and food boluses. In the first hours after birth, swallowed air rapidly fills the stomach and intestine, thus inflating the abdomen into its normal postnatal form (Frimann-Dahl et al, 1954). Randomly occurring occasional swallows of secretions are usually intermixed with air. Occasional swallows occur along with episodes of crying or speech and at times of stress. Rarely, air swallowing occurs repetitively, resulting in abnormal inflation of the gut. The elicitation and limitation of this form of excessive gut inflation are unknown. Some esophageal speakers inflate the esophagus by air swallowing; most of the aspirate air into the esophagus (Weinberg and Bosma, 1971).

Air Swallowing into the Tracheobronchial Tree

Air is also swallowed into the tracheobronchial tree by "glossopharyngeal breathing", as an alternative method of lung filling other than inspiration. This method consists of pharyngeal expansion, palatopharyngeal and oropharyngeal closure, and cephalocaudal compression of air (Dail et al, 1955). It has been designated "frog breathing" because of its similarity to the lung-filling mechanisms of the frog, which lacks a diaphragm. Glossopharyngeal breathing may be taught to poliomyelitis patients or others who have paralytic disability of the thoracic musculature. An analogous pharyngeal pumping of air into the lung was observed radiographically during birth transition (Bosma and Lind, 1960). This accessory mechanism of respiration is recognized as an emergency resource of infants. Peiper (1963) comments, "swallowing respiration is the last safeguard before death due to respiratory arrest".

Rumination, Vomiting, and Eructation

The pharynx is involved in each of these performances of oral emission from the esophagus and stomach. These performances are considered in the next section, Physiology of the Esophagus.

Respiration

Participations of the pharynx in respiration differ from those in feeding in their sensory elicitations and guidance, in their central representations, and in their motor patterns. Basically, the pharynx and the laryngeal vestibule, which is also derived from the foregut, perform as an expansile respiratory chamber, distinguished from the lower, or thoracic, chamber. Comparison of this arrangement with that of lower order vertebrates provides some perspective. In fish, the pharynx and the adjacent areas of the gill system are the only respiratory chamber. In the Amphibia, the lungs are inflated by glossopharyngeal pumping.

Studies in experimental animals demonstrate functionally separable systems of respiratory reflexes elicitable from the upper and the lower pharynx. Sniffing is elicitable by tactile stimulation of the upper pharynx or the nose (Takagi et al, 1966). Respiration may be accelerated by tactile stimulation of the palatopharyngeal mucosa. Forced expirations, on occasion accompanied by glottal occlusion or even the total action of coughing, result from tactile, chemical, or pressure stimulations of the lower pharynx or the larynx (Lumsden, 1923; Takagi et al, 1966). Sensations from pharyngeal surfaces probably elicit modulations of each respiration.

The pharyngeal motions of respiration differ in motor patterns from the peristalsis of swallowing. They are part of the agonist-antagonist pattern that is common to the rest of motor respiration, including the considerable variety of adaptive respiratory performances.

During quiet *tidal respiration* via the nasal portal in infants, the motions of enlargement of the upper respiratory chamber during inspiration and diminution during expiration are visible by radiography. The motions are increased during dyspnea. In neurologically mature persons, who have greater postural stability in the cervical area, the pharyngeal margins, and particularly the tongue-hyoid-larynx column, are positionally more stable.

The pharynx participates in each of the upper respiratory valvings, supplementary to the valvings at the larynx and the mouth. This participation is more conspicuous in infants. The motions of the pharynx during *infant cry* illustrate this well (Bosma et al, 1966). As shown the pharynx and the laryngeal vestibule constrict extensively with each cry-phonated expiration and are opened widely with the intervening dyspneic inspirations. The velum is drawn toward the posterior wall; the palatopharyngeal isthmus may be closed during strong cries. The median portion of the tongue is drawn downward as a groove. Like most infant performances, crying is repetitive in a stereotypic pattern. The details of pharynx and mouth motions vary among infants, and the acoustic pattern of the cry is highly individual (Truby and Lind, 1966).

The *speech* gestures of the pharynx and mouth are remarkably different from those of crying gestures, since they reflect the postnatal development of the anatomy and functions of the pharyngeal area. During mature speech, the hyoid and the constrictor walls of the pharynx remain stable. The motions of pharyngeal articulation are discrete in site and varied in pattern in a highly discriminate manner, which is appropriate to their voluntary control.

Certain factors of impairment of speech performance are particularly pertinent to medical evaluation of the pharynx. The performances of speech provide clinical criteria that are separate from those of feeding in cases of progressive peripheral neuropathy, which impairs sensibility or motor function, or both; myopathy; or progressive central neural or neurovascular disease.

Certain factors of impairment of speech performance are particularly pertinent to medical evaluation of the pharynx. In cases of progressive peripheral neuropathy impairing sensibility or motor function, or both; of myopathy; or of progressive central neural or neurovascular disease, the performances of speech provide clinical criteria that are separate from those of feeding.

The pharynx and mouth also participate in the expiratory valving of *coughing.* In infants, this participation occurs in the displacement pattern of general constriction, with opening of the mouth and closure of the palatopharyngeal isthmus, essentially similar to that of infant cry. In neurologically mature persons, the pharyngeal motions are similar, except for adaptations appropriate to the greater size and positional stability of the pharynx.

Another type of expiratory valving in which the pharynx and mouth participate is that of consistent valving or *occlusion of expiration* at the lips and tongue in persons having chronic pulmonary disease. This pattern intergrades in expression with grunting.

Pharyngeal Airway

The pharynx has a central role in the development of positional control, or posture, at the junction of the head and neck, in addition to its role in the development of feeding and respiration. The pharyngeal airway is achieved by the integration of several separate motor coordinations. It depends primarily on appropriate craniovertebral angulation and cervical vertebral alignment (Shelton and Bosma, 1962). It also depends on appropriate dimension and position of the mandible in relation to the midfacial skeleton and position of the hyoid in relation to the mandible. Contour and dimension of the pharyngeal airway are determined by the sleeve of constrictor muscles and by the pharyngeal palate, the tongue, and the suspension of the thyroid cartilage. During nasal portal respiration, the pharyngeal palate and tongue are in apposition. This apposition is the primary or basic site of oral closure during tidal respiration, being more persistent than closure in the lingual chamber or at the lips during sleep or narcosis and in various neurologic disorders that impair oral position.

Closure at the pharyngoesophageal segments is stable, being interrupted only during swallowing, regurgitation, vomiting, or eructation. From anatomic inference, the cricopharyngeal muscle is part of the positional, or postural, motor composite of muscles that hold the larynx in position, together with the pretracheal muscles and the suspensory muscles of the hyoid and larynx. This differential role of the cricopharyngeal muscle is indicated in spastic dystonia involving the branchial and cervical musculature. In this circumstance, the inhibition of the cricopharyngeal muscle, which is part of the swallow coordination, is abbreviated.

The sensory guidance and central regulation of pharyngeal airway maintenance are less discernible than are its motor mechanisms. Apparently, such maintenance is cued from the upper airway. With complete deflection of the respiratory stream via tracheostomy, spatial arrangements of the pharyngeal walls, particularly the tongue, hyoid, and larynx, are pertinent only to posture at the head and neck. The pharynx may or may not be open. However, the specific elicitation of the airway has not been identified. The central representation of the pharyngeal airway is probably within the postural regulatory mechanisms of the brain stem and cerebellum. However, its representations must also be separate from those of posture, since the pharyngeal airway is maintained during sleep.

The function of the pharynx as an airway is demonstrated early in development. The function is present and fully competent in viable premature infants, and the mandible, hyoid, and larynx are normally well stabilized in position at term birth. This stabilization of the pharyngeal airway is the earliest positional, or postural function of the developing human. It is the prologue of postural development at the head and neck and of the sequential cephalocaudal development of upright posture in the trunk.

The anatomic arrangement of the pharyngeal airway is different in infants than that in neurologically mature adults. In infants, the epiglottis approximates the lower margin of the palatopharyngeal isthmus. Laitman and co-workers (1977) describe the epiglottis as penetrating between the palatopharyngeal folds. Thus, the mesopharyngeal arrangement of the human infant would be in the general, or basic, pattern of most mammals in which, at any developmental age, the epiglottis penetrates into or through the palatopharyngeal isthmus (Negus, 1949). With postinfantile elongations of the pharynx, the epiglottis and larynx descend in relation to the pharyngeal palate. The physical problem of airway maintenance is thereby increased, because the column of the tongue, hyoid, and larynx is farther from its suspension attachments upon the cranium and mandible. Stability of the airway in the mesopharynx and laryngeal vestibule reflects the maturation of postural mechanisms in this region.

Evaluation of pharyngeal airway maintenance is readily accomplished but seldom performed - perhaps because the performance seems obvious. Actually, the normal posture of the head and neck in the upright position indicates normal pharyngeal airway maintenance. The person who lacks this mechanism because of motor disability has a distinctive anteriad displacement of the head in relation to the trunk, ie a "swan neck". Similarly, the observation or definite history of easy respiration during sleep is also indicative of normal airway maintenance. Persons having impairment of airway maintenance typically snore and commonly have intermittent respiratory obstruction (Weitzman et al, 1978; Guilleminault et al, 1977).

Testing Pharyngeal Airway Competence

The competence of pharyngeal airway maintenance is readily tested. During passive lowering of the mandible, while the individual continues nasal respiration, the tongue and hyoid are normally held stably forward. In persons having impairment of airway maintenance, the tongue and hyoid may recede posteriad during this maneuver, possibly impeding tidal respiration. The competence of the tongue and hyoid suspensory musculature in airway maintenance can be evaluated by applying posteriad pressure by the examiner's finger upon the hyoid externally or upon the body of the tongue within the mouth. In normal persons, the suspension of the tongue or hyoid, or both, actively resists this pressure, possibly with a palpable motion forward, against the finger. In persons who have weakness of these suspensory muscles or a general impairment of this performance, the displacement may cause occlusion of the airway.

The performance of maintenance of the pharyngeal airway is well demonstrated by its selective impairment in the syndrome described by Robin (1934) in infants. The infants with this syndrome have hypoplasia or cleft of the pharyngeal palate and retrusion and small size of the mandible without anomaly of mandibular form. They may also have glossoptosis: The tongue falls into the pharyngeal airway if the jaw is lowered and the mouth is opened while the infants are supine. Many of these infants may be cared for in the prone position until later in infancy, when the adequacy of pharyngeal airway maintenance is achieved, probably by additional developmentally achieved sensory or central mechanisms (Takagi et al, 1966).

The most common impairments of pharyngeal airway maintenance in neurologically mature persons are those manifested during sleep. A disorder of acquired impairment of pharyngeal airway maintenance during sleep has been identified as the syndrome of hypersomnia and sleep apnea (see reviews by Guilleminault et al, 1976, 1977). This occurs more commonly in males aged 40 to 60 years. Some patients are obese. The typical history is that of snoring and of apnea during sleep. Systemic and pulmonary hypertension in the waking state are also associated findings (Guilleminault et al, 1978). Cineradiography during sleep in the supine position demonstrates occlusion of the pharyngeal airway (Lugaresi et al, 1978). More recently, the site of occlusion has been further defined by cineradiography and endoscopy as being located at the palatopharyngeal isthmus and as occurring at the end of expiration, obstructing the next inspiration (Weitzman et al, 1978). The syndrome, including the associated hypertension, is relieved promptly by a tracheostoma that is open during sleep (Hill et al, 1978).

Similar symptoms and signs are occasionally found in children having obstructive hypertrophy of tonsils or adenoids (Kravath et al, 1977) or in adults having micrognathia (Coccagna et al, 1976).

Physiology of the Esophagus

Martin W. Donner

The esophagus is a tubular link between the pharynx and the stomach. It is demarcated from these adjacent units by sphincters that are normally closed except during bolus passage. The upper sphincter prevents air from filling the esophagus during inspiration, and the lower sphincter prevents gastroesophageal reflux. The principal function of the tubular esophagus is the active transport of food and drink.

The closure of the pharyngoesophageal (pe) segment, or upper esophageal sphincter, during the resting state is palpable as a resistance to penetration of the esophagoscope (Ingelfinger, 1958); its tonus is demonstrable by manometry (Dodds et al, 1975). Under normal circumstances, the segment is not visible during radiographic examination. The motor patterns of the pe segment during normal swallowing and in certain neuromuscular impairments of swallow have been described in the preceding section, Physiology of the Pharynx.

The tubular esophagus, between the sphincters, is normally empty of bolus or air. Its musculature is relaxed. Except during bolus passage, the intraesophageal pressure reflects the respiratory variations of intrathoracic pressure, being negative in reference to atmosphere.

At rest, the lower esophageal sphincter segment is closed and is characterized by manometry as a high-pressure zone (Fyke et al, 1956), defined as the difference between the intrasphincteric and fundic pressures (Fig. 14). The high-pressure zone measures 2 to 5 cm in length and relaxes soon after swallowing has commenced or after distention of the esophagus has occurred (eg retention of food bolus in the esophagus). The high-pressure zone is located partially below and partially above the diaphragm. In the center of this zone, the direction and amplitude of the fluctuations in pressure change with breathing. This point of respiratory pressure reversal (Code et al, 1958) occurs at the level of the diaphragmatic hiatus. It is identifiable during withdrawal of a pressure-sensitive device from the stomach into the esophagus and serves as a convenient physiologic landmark (Rinaldo and Clark, 1964). Employing manometry with continuous perfusion of the recording catheters, Cohen and Harris (1971) reported mean lower esophageal sphincter pressures of 20.4 ± 2.1 mm Hg above the gastric pressure. These pressures exceed the values obtained with nonperfused catheters

(Hellemans and Vantrappen, 1974). Variations in the manometric pressures in this area correlate well with the abnormality of gastroesophageal reflux. Low resting pressures, less than 6 mm Hg, were recorded in patients with serious symptoms of gastroesophageal reflux by Cohen and Harris (1971). In most reported series (Skinner and Booth, 1970); Benz et al, 1972; and others), however, there was at least partial overlap of resting lower esophageal sphincter pressures in patients with or without reflux.

Contributing to the strength of the lower esophageal sphincter are gastrointestinal hormones such as gastrin (Bennet et al, 1967) and secretin (Cohen and Lipshutz, 1970). Of particular clinical significance are the reports by Castell and Harris (1970) and Castell and Levine (1971) concerning the link between gastric acidity, gastrin production, and gastroesophageal sphincter strength. Acidification of the antrum, which inhibits gastrin production, lowers sphincteric pressure, whereas alkalinization of the antrum increases the pressure. The beneficial effect of antacids and a protein meal on lower esophageal sphincter pressure has been credited to the release of endogenous gastrin.

During *deglutition*, the tubular esophagus receives the bolus from the pharynx and actively transports it to the stomach (Fig. 15). The pharynx and esophagus function as a unit in concert with their sphincters. The transport mechanism in the tubular esophagus, which is initiated by a single swallow, is a coordinated progressive contraction with participation of the entire esophagus. In humans, this "primary peristaltic wave" is centrally mediated. Local stimulation of the esophageal wall in the form of a solid food particle retained midway in the gullet usually results in a "secondary peristaltic wave". Such a wave may also be triggered by electrical stimulation, balloon distention, or reflux of gastric contents into the esophagus. The progression velocity and the radiographic as well as manometric appearance of secondary peristaltic waves are the same as in primary peristalsis (Siegel and Hendrix, 1961). A persistent, often rather powerful muscular contraction may be observed when a large, fixed obstructing bolus is arrested in the esophagus. This esophageal propulsive force differs from the secondary peristalsis associated with mobile or collapsible boluses (Winship and Zboralske, 1967).

A rapid succession of pharyngeal swallows is associated with a single peristaltic wave in the esophagus. Only one peristaltic wave descends on the esophagus, starting after the last swallow. The gastroesophageal sphincter relaxes in response to the first swallow and remains relaxed during the entire series and until the last contraction has terminated. The peristaltic contraction elicited by the first swallow as it progresses in the esophagus stops or fades out if a second pharyngeal swallow occurs.

In humans, the speed of peristaltic progression varies only slightly; primary waves traverse the esophagus at a rate of 3 to 4 cm per second.

Clinical Manometric Studies of Deglutition

Multichannel perfusion techniques or intraluminal strain gauge systems (Dodds et al, 1975) have found increasing acceptance in the clinical evaluation of disorders of esophageal contractility and sphincter tonus. Manometry can be correlated with cineradiography of barium swallows. The small diameter of the catheters used for esophageal manometry makes it possible to combine them in a single probe and hence to measure the pressures at different levels in the esophagus simultaneously. Usually a distinction is made between the "resting pressure" and pressure changes elicited by deglutition occurring "spontaneously". By using a multiple input system, the sequential, simultaneous, or repetitive nature of pressure variations can be evaluated. To measure the pressure profile of the gastroesophageal sphincter, the catheter can be pulled back from the stomach step-wise through the sphincter segment. At each 0.5- to 1.0-cm interval, the pressures can be measured during several respiratory cycles, using a "slow pull-through" routine. Or the catheter may be drawn rapidly and continuously through the sphincter while the respiration is arrested for a moment; ie the "fast pull-through" routine (Pelemans and Texter, 1974).

In summary, the following issues may be addressed by manometry:

1. Localization and resting pressures of the upper and lower esophageal sphincter.

2. Relaxation characteristics of each sphincter.

3. Resting and deglutition pressures in the tubular esophagus.

4. Response of esophageal peristalsis and sphincter tone to pharmacologic agents.

Radiologic Examination of the Esophagus

Fluoroscopic examinations using barium contrast may be recorded on video tape or motion picture cine film for subsequent review and analysis. Permanent recording is essential because swallows pass through the esophagus and sphincter segments rapidly and the abnormalities may be complex. Consecutive examinations should be compared with each other, and correlation with manometry and other study methods is often essential. It is important to observe each progressive peristaltic contraction responding to a single pharyngeal swallow as it traverses the entire length of the esophagus, because a series of pharyngeal swallows results in the interruption of each preceding peristaltic wave until the last swallow in a series has occurred. Combined cine-manometric studies have shown that the lower esophageal sphincter relaxes in advance of the bolus; in most individuals, this occurs at the time when peristaltic waves have reached the level of the clavicle. The peristaltic wave is immediately followed by contraction and closure of the lower esophageal sphincter.

Sometimes, it is useful to employ pharmacologic agents for diagnostic purposes, eg bethanechol chloride (Urecholine) in patients with achalasia and acid barium in those with a history of "heartburn". In addition, pharmacologic agents may be used in follow-up patients under treatment for diffuse esophageal spasm (eg nitrites) or moniliasis (eg antifungal medication). In these cases, cineradiographic observation is indicated. In all patients with symptoms of dysphagia, both the esophagus and the pharynx should be examined, since the subjective site of sensation of obstruction indicated by the patient frequently does not coincide with the actual site of bolus retention. In fact, the patient is wrong more often than right in identifying the site of an organic or functional abnormality. In 30 per cent of cases of gastroesophageal reflux, patients localized the discomfort exclusively to the neck ("high dysphagia") (Cherry et al, 1970). Similar discrepancies between the site of symptoms and site of pathology have been described for achalasia, carcinoma of the cardia, and other obstructive disorders of the esophagus (Edwards, 1976).

Abnormalities of the Esophagus

Patterns of Motor Disturbances of the Esophagus

In general, dyskinetic motility of the tubular esophagus may be expressed in the form of (1) nonperistaltic, spastic contractions, usually involving short segments of the esophagus; or (2) lack of tone, affecting the esophageal wall throughout its entire length or partially, ie either the smooth or the striated muscle portions (Fig. 16). Segmental spastic contractions are nonprogressive and, hence, differ from normal propulsive primary and secondary peristalsis. They narrow the lumen in the involved longitudinal segment of the esophagus and occur when chemical and other inflammatory (eg fungal) disorders affect the esophagus or when the esophagus becomes "acid sensitive" in patients with gastroesophageal reflux. Occasionally, segmental spastic contractions occur in response to disorders involving the mediastinum. Atony is associated with dilatation of the esophagus and frequently also with alteration or complete absence of peristalsis. The most commonly observed disorders in this category are scleroderma and achalasia. In both disorders, the esophagus usually contains considerable amounts of air, and in achalasia an unswallowed bolus of saliva or food is retained.

One of the most frequent abnormalities associated with esophageal motility disturbance is gastroesophageal reflux (Fig. 17). In this common disorder, lower esophageal sphincter pressure, as determined by perfusion manometry, is considerably lower than in normal subjects or in hiatus hernia patients without reflux (Cohen and Harris, 1971). According to these authors, lower esophageal sphincter resting pressure in reflux patients does not exceed 6 mm Hg. However, Pope (1967), Bennett (1973), and Benz and co-workers (1972) did find a certain overlap between patients with and without heartburn. From these investigations, it is assumed that reduced resting pressure in the lower esophageal sphincter plays a major role in patients with reflux symptoms. As a consequence of increasing episodes of reflux, the esophageal epithelium is altered so that it becomes less of a barrier to the diffusion of gastric acid and other noxious substances, such as bile acids. Presumably, these substances stimulate nerves in the lamina propria, resulting in neural impulses that delay the secondary peristaltic waves, which normally empty the esophagus of residual bolus.

The motor response of the esophagus to an acidifed bolus can be evaluated by manometry, by cineradiography, or by a combination of these methods (Fig. 18) (Donner et al, 1966). The results obtained from these demonstration methods are closely correlated with the symptoms. In asymptomatic persons, the response to a swallow is essentially the same, regardless of the pH of the bolus. One third of all patients with proven gastroesophageal reflux localize their symptoms in the neck, giving rise to "high dysphagia" and "globus sensation" (Fig. 19). The symptoms occur because spastic contractions of the middle or upper esophagus thrust esophageal contents in an upward direction against the pharyngoesophageal sphincter segment (Cherry et al, 1970) and, potentially, into the pharynx.

This pathophysiologic mechanism in patients with reflux esophagitis may lead to the formation of a pharyngeal diverticulum of Zenker above the pharyngoesophageal segment. In these patients with midesophageal contraction and bolus displacement against the closed pharyngoesophageal segment, hypertrophy of the cricopharyngeal sphincter fibers eventually develops. Intraluminal pressure rises in the pe segment, and concomitantly in the hypopharynx, with the result of outpouching of mucosa in a known area of physiologic weakness (Killian's dehiscence) (Delahunty et al, 1971).

When esophageal contents are regurgitated above the cricopharyngeal sphincter and are subsequently aspirated into the larynx, contact ulcers of the larynx may develop. The acidic material from aspirated gastroesophageal contents may cause inflammation of the vocal cord mucosa with subsequent formation of granulation tissue. These benign ulcerative lesions involve the posterior portion of the vocal cords. This cause of vocal fold contact ulcers is alternative to that of vocal abuse. Treatment with antacid medication has led to healing of the ulcers (Cherry and Margulies, 1968).

Diffuse Esophageal Spasm

Segmental contractions of the esophagus are seen in a neuromuscular disorder of unknown etiology. In this condition, the pharynx and the upper esophagus contract with normal progressive peristalsis, but the lower two-thirds of the esophagus reveal repetitive simultaneous contractions in response to a swallow. The pressure in the lower esophagus may be increased or may be normal. Manometric tracings during deglutition display simultaneous (nonsequential) pressure peaks of repetitive and biphasic waves and of giant waves. In some patients, pain occurs during these contractions. However, very abnormal tracings can be recorded at a moment when the patient is asymptomatic. Primary peristaltic waves in response to swallows may be completely replaced by simultaneous repetitive contractions or may occasionally traverse the entire esophagus. If patients with severe symptoms fail to respond to drug therapy, pneumatic dilatation, as used in achalasia patients, may be successful. The patient may become free of symptoms with a markedly less disordered motility pattern, or esophageal peristalsis may gradually return to normal (Bennett et al, 1970). During fluoroscopy, one can observe that the barium-filled esophagus is suddenly narrowed by a strong contraction. The walls of the esophagus are distorted and assume a corkscrew-like configuration, sometimes giving the appearance of multiple esophageal diverticula. The contractions may lead to shortening of the esophagus, resulting in a sliding esophageal hiatus hernia. Inhalation of amyl nitrite or the sublingual application of nitroglycerin sometimes leads to symptomatic and radiologic improvement.

Achalasia

In this condition, progressive peristaltic waves in the body of the esophagus are characteristically absent. The lower esophageal sphincter is unable to relax in response to a swallow. One of the most striking abnormalities is the considerable dilatation of the tubular esophagus observed during fluoroscopy. A fluid level may be detected in the middle or upper portion of the esophagus, depending on the tightness of the lower esophageal segment. The higher the support level of fluid, the tighter the lower esophageal sphincter contraction.

Manometry is a useful procedure to confirm the diagnosis, which is suggested by clinical and radiologic criteria. In cases that pose problems in differential diagnosis, manometry is essential to exclude other functional disorders of the esophagus (Fig. 20). Pharyngeal swallow is followed by pressure waves that occur simultaneously and often repetitively over the entire length of the esophagus. They usually become feeble, with a small amplitude, or may entirely disappear as esophageal dilatation increases. Using a perfused catheter system, Cohen and co-workers (1971) found a markedly increased sphincter pressure in achalasia patients. This high resting pressure has been ascribed to gastrin hypersensitivity. Serum levels of gastrin are not elevated in patients with achalasia, and the sphincter pressures can be reduced to normal by acidification of the gastric antrum, which inhibits gastrin secretion.

In order to exclude disorders similar to achalasia such as obstruction of the distal esophagus by stricture or tumor, bethanechol chloride or methacholine chloride has been used as a pharmacologic test. The esophagus in patients with achalasia is unduly sensitive to these agents when given intravenously in a dose of 6 to 10 mg (Kramer and Ingelfinger, 1949, 1951), whereas in normal subjects these agents do not cause a significant response. In patients with achalasia, these drugs produce a painful, tonic, lumen-obliterating contraction of the esophagus beginning shortly after the injection and lasting up to 30 minutes. This contraction may be recorded manometrically. Increases in pressure in the esophagus may reach 20 cm of water or more, and simultaneous repetitive pressure waves are superimposed on it. Pressure in the gastroesophageal sphincter also increases. During fluoroscopy, the esophagus is seen to contract forcefully in a nonpropulsive fashion, and barium is displaced back into the upper esophagus and into the pharynx. Patients with achalasia undergoing such tests frequently experience substernal pain, which subsides promptly upon the administration of 0.6 to 1.0 mg of atropine. Since the bethanechol chloride test may not necessarily be positive in all cases of achalasia and since it may be falsely positive, endoscopy with biopsy is recommended. A number of patients with symptomatic diffuse esophageal spasm have been reported as being hypersensitive to methacholine chloride as well. This has led to the assumption that, in some patients, diffuse esophageal spasm may actually represent an early manifestation of achalasia.