ORTHODONTIC AND BIOLOGICAL CONSIDERATIONS OF DEGLUTITION, ORO-LINGUO-FACIAL MUSCLE FUNCTION, AND TONGUE THRUST - DIAGNOSIS

VOLUME I

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TABLE OF CONTENTS

Page

VOLUME II

CHAPTER

Page

ILLUSTRATIONS

CHAPTER 1 INTRODUCTION

1.1 Problem Statement, Definitions, and Limitations of Study

1.2 Setting of Study

1.3 Purpose of Study - Hypothesis

1.4 Outline of Study

CHAPTER 1

INTRODUCTION

1.1 Problem Statement, Definitions, and Limitations of Study

This treatise is principally concerned with the oral myofunctional disorder of tongue thrust. This disorder has been described in various ways, such as 'deviate swallow', 'infantile swallow', and 'abnormal swallow' to name a few. The term 'tongue thrust' has been adopted throughout this study, mainly because of its greater usage among authors, and since it gives a more accurate description of the lingual behaviour about to be discussed. 'Tongue thrust' and 'tongue thrusting' are used in preference to 'tongue thrust swallow' or 'tongue thrust swallowing' because this behaviour is generally thought to be less associated with the act of swallowing and more with the resting posture of the tongue. 'Thrust' is still an inappropriate word since the tongue is not really 'thrusting' during rest. However, it must be remembered that 'thrusting' in this instance is still a mild but continuous lingual pressure factor. The significance lies in whether or not this 'thrust', either during swallowing and other functional behaviours, or during rest, is responsible for, contributes to, or is a consequence of, the development of a malocclusion.

Tongue thrust, therefore, has been defined in terms of:

(1) Its effect on the occlusion, i.e. causing or contributing to a malocclusion, and in what location - anterior, posterior, unilateral, bilateral; and

(2) Its being an abnormal and continuous habitual (i.e. unconscious) activity.

Various authors have attempted to define it. Boucher (1974) described it simply as the "pressing of the tongue against or between the maxillary and mandibular teeth as a habit pattern". Hanson (1979a) offered a more precise definition: "When, in a resting position, the anterior or lateral portions of the tongue contact more than half the surface area of either the upper or lower incisors, cuspids, bicuspids, or protrudes between them; or when during the swallow of any two of the three media (liquids, solids, and saliva) there is a visibly observable increase of (1) force; (2) degree of protrusion; or (3) amount of surface area of the teeth contacted by the tongue, there is a tongue thrust." Proffit (1977) preferred the term "anterior tongue positioning". However, this did not take into account the posterior interdental positioning of the tongue in some individuals.

Controversies surrounding the existence of, and treatment for, tongue thrust have been with us for many years, especially since the early 1950's. Being such a contentious topic, it is natural that today there are no well-defined guidelines for the management of patients with tongue thrust, except in areas where, it may appear, a large component of diagnostic bias is evident.

The writer's interest in this subject was first aroused with the management of a tongue-thrusting patient exhibiting severe bimaxillary protrusion over ten years ago. Consequently, this interest has become greater with the opportunity of treating these types of patients over the past six years. Also, being able to work with those of different professional disciplines has helped to see the problem from a more neutral viewpoint.

I have attempted to limit this study, as much as possible, to the relevant biological, physiological, and orthodontic considerations of tongue thrust behaviour, and to the overall oral muscular environment. Barnwell (1977, 1978) published a three part bibliography on "Oral Myology, Oral Myofunctional Disorders, and Oral Myofunctional Therapy". He cited over 900 references, indicating the extent of this subject. Much more has been written in the seven years since then. The limitations imposed on this study, therefore, have been aimed to prevent the discussion from delving too far into other controversial subjects such as craniofacial growth concepts and 'form-versus-function' arguments.

1.2 Setting of Study

As mentioned, this topic has been a controversial one for some time. However, ten years ago a rather disturbing statement was published (J. Am. Dent. Assoc., 1975; Am. Speech and Hearing Assoc., 1975) by the Joint Committee on Dentistry and Speech Pathology - Audiology, later to become known as the "Joint Committee statement" (Hanson, 1976b; Pierce, 1980). It was disturbing to those orthodontists and speech/myofunctional therapists working in the field of myofunctional therapy for the correction of tongue thrust activity. The reasons for the consternation were twofold. Firstly, its impact was to discredit the findings of investigations up until that time, which had explored the diagnosis of tongue thrust behaviour, and which sought to lead towards more effective treatment for this entity. Secondly, instead of promoting further research, which it had urged, it had the opposite effect, and a shadow was cast over the whole concept of myofunctional therapy together with research associated with it. As Pierce (1980) later commented, "what respectable researcher is going to become involved in such a clandestine and controversial subject?"

One of the major criticisms contained in the statement was that oral myofunctional therapy had not been proven to be effective in tongue thrust correction. This was stated in the face of two important considerations:

(1) there had been a number of studies performed which had examined directly the causal nature and the effectiveness of treatment for tongue thrust; and

(2) to what extent can corrective treatment, of any kind, be 'proven' to be effective? Furthermore, what are the scientific criteria associated with the proof and effectiveness of <u>any</u> therapeutic measure?

Since the publication of the statement, there has been a further polarising of opinion. On one side, some orthodontists (Proffit, 1977; Tulley, 1980) have been extremely influential in convincing their colleagues and others that tongue thrust is an insignificant entity on the whole, except in extremely rare instances. On the other side, some speech pathologists and/or 'oromyofunctional therapists' have implicated tongue thrust in the etiology of many orthodontic and orofacial disorders, and have made sweeping claims that their particular variations on myofunctional therapy have been extremely effective.

This polarisation is reflected in the literature. In the orthodontic journals, little mention is now made of tongue thrust and even less of oral myofunctional therapy. Whereas, a number of texts on tongue thrust have emerged (Garliner, 1976; Barrett and Hanson, 1978; Pierce, 1978; Goldberger, 1978a) and in the speech pathology journals, much more has been published. In fact, following the Joint Committee statement, a separate journal appeared - the Journal of Orofacial Myology, a revised version of the Journal of Oral Myology, which had as its intention the publication of as much material as possible on the topics of tongue thrust and oral myofunctional therapy. Another journal, on the fringes of orthodontic acceptance - the International Journal of Orthodontics - was revamped and has since published quite a few articles on these topics.

For the orthodontist, a dilemma has arisen. Should s/he accept the authoritative (and sometimes dogmatic) opinions of some influential orthodontic researchers, who have been critical of the emphasis placed on tongue thrust behaviour, on the basis of the evidence they have presented; or should their evidence be questioned and examined for flaws, and their conclusions checked for validity? Certainly, the circumstances surrounding the Joint Committee statement seem very mysterious. The members of the Committee have not been identified, and the full reasons for their findings have never been published. Yet this statement seems to be the basis of current criticism of tongue thrust investigation (Proffit, 1977).

Conversely, should the orthodontist be swayed by the findings of well-published speech and myofunctional therapists, on the efficacy of (a) the methods of diagnosing tongue thrust behaviour, and (b) the administration of appropriate treatment regimens? How plausible is the evidence supporting tongue thrust correction programs? Are the myofunctional therapists (and this may include a number of orthodontists) a group concerned with the detection and correction of tongue thrust behaviour, the significance of which has been largely unrecognised by the orthodontic establishment as a whole, especially in recent years? Or are they a body of self-interested charlatans (as might be implied by some authors) indulging in the practice of therapeutic hoodwinking? This treatise will attempt to shed some light on these issues.

1.3 Purpose of Study - Hypothesis

The thoughts expressed by Strang some time ago (1943) encapsulate the author's reasons for attempting this treatise:

> "Abnormal Swallowing Habits - Without a doubt these comprise one of the most common and influential muscular perversions that the orthodontist encounters. They can never be successfully combated in all cases until we know just how and why they originated and what are the primary causes that led to the establishment of the perversion. These factors known, this powerful and insidious cause can be attacked in its initial stage, where it naturally is most vulnerable, and thus the habit eliminated before it has had the opportunity to work its devastating effects upon the dental arches."

The purpose of this study, therefore, is to examine critically both sides of the controversy surrounding tongue thrust behaviour. This discussion will deal with the diagnostic aspects of tongue thrust, and it is intended that the therapeutic aspects of the overall discussion will be dealt with in a following study, especially oral myofunctional therapy for the correction of tongue thrust.

Research may be defined as the "diligent and systematic enquiry or investigation into a subject" (The Macquarie Dictionary, 1983). This project aims to adhere to this concept. In addition, it is based on the hypothetico-deductive concepts of Popper (Magee, 1979; Miller, 1983). The hypothesis is:

<u>Tongue thrust is both a biological entity and an identifiable cause of specific types of malocclusion.</u>

1.4 Outline of Study

This discussion is presented in two volumes:

Volume I, incorporating Chapters 1, 2, and 3, covers the biological considerations of lingual behaviour, especially in relation to deglutition (the act of swallowing), oro-linguo-facial muscle function, and tongue thrust.

Volume II includes Chapter 4 - a discussion on the orthodontic considerations of aberrant lingual behaviour; Chapter 5 - the conclusions drawn from this study, and lastly the Bibliography.

CHAPTER 2

DEGLUTITION: PURPOSE, STRUCTURE, AND PROCESS

2.1 Normal versus Abnormal Swallowing

In order to examine in detail the nature of the abnormal swallowing pattern and tongue thrust in particular, it is necessary to know how abnormal patterns deviate from the normal and to what extent. Therefore, a thorough grounding in what constitutes a normal pattern is fundamental to the understanding of the mechanisms of aberrant behaviour.

This view was held by Hedges, McLean, and Thompson (1965) who pointed out that before the effect of abnormal function in swallowing can be determined, or before the degree of aberration necessary to lead to an abnormal relationship of teeth can be determined, a definitive knowledge of normal function is necessary.

Unfortunately the delineation of abnormal from normal is not clear. In comparing the finer details between normal and abnormal swallowing it becomes especially difficult to separate one from the other. In fact, Cole and Cole (1980) contend that dividing deglutition patterns into 'normal' and 'abnormal' is like dividing personalities or philosophies on the same basis and makes no more sense to do so. These authors emphasise the change in the deglutition pattern in the individual, since patterns of deglutition vary enormously among individuals. They point out that certain aspects of the deglutition pattern are consistent not only from day to day but from year to year. However, they assert that changes in the deglutition pattern are detectable from early infancy to early adolescence.

However, Barrett and Hanson (1978) show that, in broad terms, it is not difficult to distinguish between normal and abnormal. As they point out, the term 'normal' should not be equated with the term 'average'. This is an important concept since, as will be seen later, the incidence of "abnormal swallowing" varies with age. These authors point out that even though 51% of the population perform in a certain manner, it does not make their behaviour normal. As an example they cite the incidence of smallpox, where at one time over 50% of children experienced it, yet this did not make smallpox a healthy or normal condition. The incidence of dental caries may be an even better example (Godfrey, 1985).

Therefore 'normal', as used in the present context, is taken as meaning "the conforming to some ideal norm or standard" (Blakiston's Gould Medical Dictionary, 1979) rather than being "the average or mean" (The Macquarie Dictionary, 1983).

Cole and Cole (1980) prefer to use the terms "typical" and "atypical" rather than "normal" and "abnormal" in describing swallow patterns. They use "atypical" to emphasise the point that a great number of individuals may have swallow patterns that are distinctly non-typical yet present with no obvious sequelae of those swallow patterns; furthermore, the atypical swallow patterns in these individuals seem to be "pathognomonic of absolutely nothing". These authors go on to use the term "atypical" swallow pattern to refer specifically to the tongue thrust swallow pattern.

However, for the sake of consistency and clarity, and in the light of the overwhelming usage throughout the literature of the use of the terms normal and abnormal, in the present context, it would therefore be reasonable to use normal and abnormal as defined above. As Barrett and Hanson (1978) put it "... since the aberrations with which we must deal are, in most cases, so different from normal behaviour as to become apparent."

An investigation into the physiology and function of normal swallowing is now in order.

2.2 Purpose of Normal Swallowing

It has been stated (Moss and Rankow, 1968; and Moss, 1968, as quoted by Scott, 1969) that the head and neck consist of a number of relatively independent and yet integrated functions: digestion, respiration, speech, gustation, olfaction, audition, balance, vision, and neural integration. Of these nine functions, the oral cavity is the site of five, which gives some idea of its importance.

The oral cavity's functions include mastication, reception and storage of food, digestion, swallowing, speech, taste, and tongue-lip-palate tactile perception. Other functions, suppressed or reduced in significance in the human oral cavity, are defence and offence in relation to potential enemies (the expression of emotions being of importance still [Darwin, 1872]; 'thrusting' of the tongue can still be a method of expressing contempt), the obtaining of food, paralysing or killing prey, and the transportation of objects, such as bones, sticks, articles of food, and offspring. In the human species many of these functions have been taken over by hands and hand-made and -used artifacts (Scott, 1969).

Of the tongue, Barrett and Hanson (1978) observe that it possesses a greater variety of skills than any other part of the body. It controls taste, creates air currents that suck in liquids, "supervises" dental development, escorts and directs the voice into articulate speech and is the infant's bridge between the internal and external milieu, "the compass by which it explores its new world". The tongue also "pilots" food between the teeth in mastication and "steers" it into the pharynx in deglutition.

Accordingly, Jorgenson (1983) states that the tongue is one of the most complex organs of the body. He states that it must be that way to accommodate its function in taste, chewing, speech, and swallowing.

Scott and Symons (1971) note another role besides those of mastication, swallowing, and speech - that of oral hygiene. They point out that the tip of the tongue can sweep over the vestibular surfaces of both upper and lower dental arches as well as their lingual and occlusal surfaces. It can also explore and cleanse the vestibule and the retro-molar areas.

Du Brul (1980) notes that the human oral apparatus is a special complex built to perform two crucial functions, one of which is peculiar to Man:

(1) it is a food processing device in <u>feeding</u>, and

(2) it is a major part of a sound processing device in the specific form of communication - <u>speech</u>.

Taking (1) feeding, Du Brul notes that there are three essential features incorporated:

(a) an input device,

(b) a processing mechanism, and

(c) an output device.

The three separate performances in normal feeding are:

(i) movements of taking food into the mouth,

(ii) movements for the preparation of the bolus, and

(iii) movements of swallowing.

These are so integrated as to overlap within the oral cavity. Movements for taking food into the mouth depend on the consistency of the food. Liquids are brought in by sucking which is separable into infantile suckling and adult drinking. Solids are pulled in by plucking from fingers or feeding utensils. Since little preparation is needed for the passing of liquids through the oral cavity, the processing activities for liquids and solids are different. Swallowing activities for liquids and solids also show differences and swallowing behaviour is further influenced by the size and consistency of the bolus. The most conspicuous feature of the entire swallowing system is the nature of the crossing of air and food channels, which is discussed later.

According to Hiiemae, Thexton, and Crompton (1978) food is consumed in order that its constituents can fulfil the metabolic needs of the individual. They observe that in the simplest case, and for that matter in most vertebrates, food is transferred more or less directly from the external environment through the mouth and pharynx to the digestive tract. The rationale for the peculiarly mammalian pattern of intraoral mastication is the mastication of food from its initial particle size or consistency to one acceptable for swallowing. As far as mastication is concerned, it is mechanical digestion and the mixing of food with salivary enzymes which are partly responsible for chemical digestion - the process by which food is prepared for later chemical breakdown in the gastro-intestinal tract. Furthermore, these authors state that unlike other ongoing activities mastication is "self-extinguishing". Once food has been rendered acceptable (whatever that may mean in practice) mastication ceases, a bolus is formed and is then swallowed. Hiiemae et al. see the <u>act of swallowing</u> itself as a <u>transport phenomenon</u>. When ingested food first enters the mouth, its consistency is assessed to decide whether or not immediate transport to the fauces with consequent reflex swallowing is the appropriate course of action. This is discussed in a later section.

Roth and Calmes (1981) note that in addition to its alimentary function, swallowing may also serve as a <u>protective reflex of the upper airway</u>, both in protecting the airway and preventing reflux. They divide the muscles used in swallowing into "obligate" and "facultative" muscles. The facultative muscles show a variable participation in swallowing and may be sensitive to sensory manipulation and maturational changes. They go on to say that mastication, suckling, and swallowing are themselves components of even more complex behaviours. These are associated with feeding and drinking, which are particularly dependent on the function of higher centres of the brain.

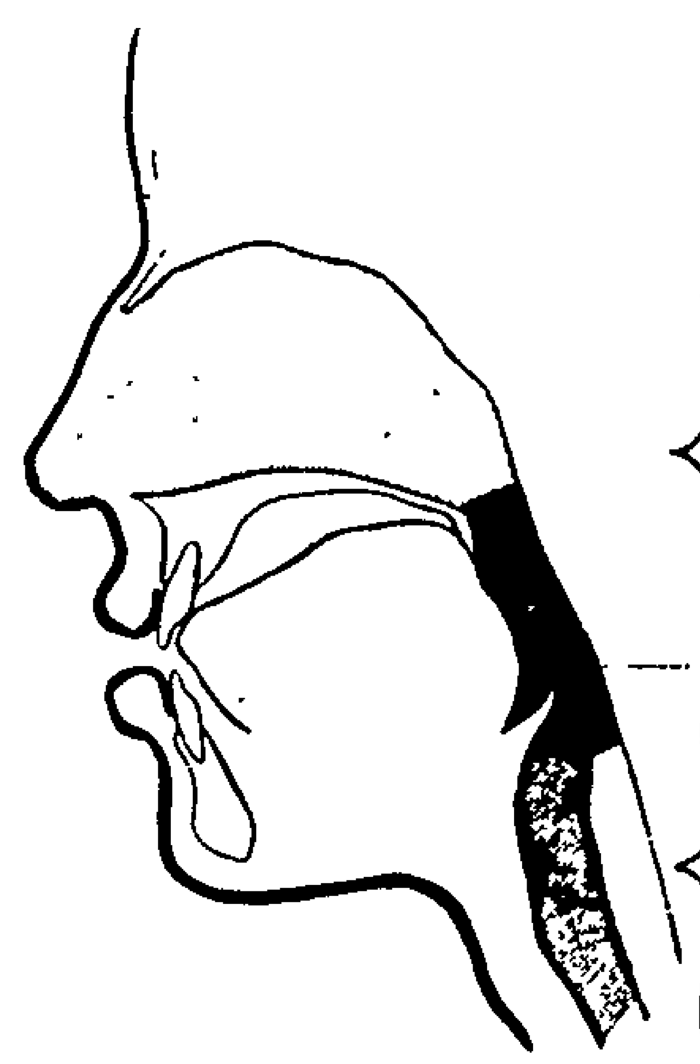
Dubner, Sessle, and Storey (1978) also see swallowing not only as part of alimentary behaviour, but also serving as a protective reflex of the upper airway. Swallowing initiated from the larynx protects the larynx from invasion by saliva, liquid bolus residues, oesophageal regurgitation, and nasopharyngeal and tracheal secretions, especially during periods of upper airway infection. They include swallowing with other upper airway protective reflexes such as apnea, sneezing, sniffing, glottic closure, and coughing and cite Kahn (1903) as the first to suggest that swallowing protected the airway. Kahn found that water stimulation of the larynx is a most effective means of initiating swallowing from the larynx of several species of animals. Storey (1965) later found that this reflex activity was initiated by water excitation of the laryngeal tactile receptors. Swallowing, he suggested, may clear small quantities of aqueous solutions from the glottic area to prevent aspiration into the lungs. Brodie (1971) also stressed the importance of the respiratory area, saying that it is the most critical and most closely guarded of the body's systems. "Robbed of oxygen, man can survive only for seconds." This view was reflected and enhanced by Thurow (1975) when he related the human being's survival to that of energy intake and consumption. The acquisition of air is vital so that the energy stored by the ingestion of food can be released. Thus acquisition of air can be regarded as the major factor in the chain of survival. "Stored oxygen will be depleted in a matter of minutes, so the intake of air must always have priority over the intake of food." Storey (1976), on this point, states that respiratory reflexes and airway protective reflexes will always pre-empt the masticatory and swallowing reflexes when the occasion arises. This is a further reflection of importance of an intact airway.

Watson (1982a) in discussing craniofacial growth writes of the vital functions of neural integration, respiration, digestion, vision and balance as related to posture, and speech - and of their relationship to growth of the oral cavity. He observes that the growth of the oral cavity is essential for respiratory needs and that all other tissues and organs adapt themselves to this need.

Thomas (1976) was another author who pointed out that the oral cavity participates in a large number of physiological activities including prehension, gustation, digestion, mastication, lapping, sucking, stereognosis, vocalisation, water balance (thirst), and reflection of the organism's emotional set. Dellow (1976) presented a convincing case in support of the theory that these activities (above) originated with, and have evolved from, the food and water needs of the organism. He went even further in advocating the corollary of this: namely that food is the most important influence in determining the organisation of the brain and the behaviour that the brain organisation dictates. Dellow pointed out that whereas mastication is not essential to all forms of food intake or to a successful life, deglutition is a much more general phenomenon. Furthermore, mankind must always swallow, even though the need for mastication seems to be diminishing. Dellow also refers to another purpose of swallowing, that of survival in the neonatal period. Amniotic fluid has been found to be drunk by the foetus. Indeed, the daily volume of amniotic fluid swallowed shortly before birth matches that of mother's milk ingested just after birth. These performances can be regarded as training for the crucial act of suckling in the post-natal period. He postulates that there might be some learning involved in, at least, the act of suckling, parallelling intrauterine developments in muscles, nerves, and the central nervous system.

Storey (1976a) also sees swallowing essentially as an airway protective reflex. Swallowing activity engages the pharynx - a region which serves an obligatory respiratory and alimentary role. It is in the pharynx that the two tracts cross (Fig. 1). Above the pharynx the airway is dorsal to the alimentary tract - below the pharynx the airway is ventral. This crossing has greatly complicated the organisation of upper alimentary and airway reflexes. An important feature of the respiratory pharynx is the base of the tongue, which forms its ventral wall. The tongue, while manipulating the bolus in mastication, is also serving as the anterior wall of a functioning pharyngeal airway. During swallowing the tongue briefly relinquishes this respiratory role to propel the bolus, piston-like, into the pharynx which also momentarily relinquishes its respiratory function.

One other purpose which swallowing serves that bears an enormous importance in the area of airway protection and maintenance is that of keeping the pharynx moist. Together with removing excess saliva, swallowing serves to keep the mucous membranes of the pharyngeal tissues well lubricated. This was observed by Truesdell and Truesdell (1937) and Rix (1946) but oddly has not been a feature of modern authors. A moist pharynx will function better from an immunological point of view for, although air is warmed and humidified while passing through the nasal structures, it is still possible for the pharynx to dehydrate. This in turn hampers the efforts of the microcilia of the airways to repel foreign material. If the pharynx is not kept moist the airways are then threatened with infectious and inflammatory agents which could lead to increased activity in the epipharyngeal lymphoid tissues and possible enlargement of these tissues (Browning, 1982).



	Effector sites	Supportive reflexes	Protective reflexes
Upper airway	nose	sniffing	apnoea / sneezing
	pharynx	airway maintenance	sniffling
	larynx	airway maintenance	apnoea / glottic closure swallowing / coughing
Alimentary tract	mouth	suckling mastication	spitting
	pharynx	swallowing	gagging
	oesoph-agus	swallowing	vomiting

Fig. 1 Alimentary and upper respiratory reflexes. Effector sites giving rise to supportive and protective reflexes of the upper airway and alimentary tract. (Storey, in Sessle and Hannam, 1976)

The purpose of normal swallowing then, is related to many other lingual and paralingual activities. To isolate swallowing is not to appreciate the purposes of the tongue and swallowing in context. Swallowing may then be seen in a broader perspective - its biological perspective.

The biological significance of the lingual musculature according to Vig (1975) lies in the functions of respiration and swallowing, with respiration being of primary importance. Most significantly, from an orthodontic view, if the role of the lingual musculature is related to respiratory needs firstly, and digestive needs secondly, then the effects of adaptation of posture and changes in patterns of motor behaviour in relation to these needs may necessarily "create malocclusion" and also "determine the limits and the long term stability of treatment".

2.3 Anatomy - The Muscular System

"You will take the measure of all the muscles and learn their functions,
who moves them, and how they are implemented."
Leonardo da Vinci (Anat. B27r)

In order to understand the overall integration of functional components that participate directly or synergistically in normal swallowing it is necessary to review the muscular components and their interrelationships.

I must point out that it came as a shock to find that the science of anatomy was still so incomplete in the oral and paraoral regions. What I had envisaged as being a straightforward description of these components and their interrelationships turned out to be far more abstruse because of the lack of cohesion among the authors - hence the length. That the science of gross human anatomy is so incomplete became less surprising after further investigation (Encyc. Britannica, 1985) revealed a decided lack of uniformity of anatomical nomenclature up until the last twenty years and this, to some extent, is still evident today. Historically, the problem has been one of a lack of communication. A legacy of different languages - Greek, Latin, German, Arabic, Hebrew, and English, having been just one factor.

Perhaps the following section then, could be regarded as a possible addition to the current literature, in a contemporary attempt to coherently describe and discuss the gross functional muscular anatomy for the dental practitioner/orthodontist, with particular reference to the lingual structures.

The first section on Embryology deals solely with the tongue, since (1) this is the main organ of interest in this discussion, and (2) it is important to be aware of the neuro-motor relationships between the intrinsic and extrinsic components of the tongue, and the other related functioning components of the pharynx (Fig. 4). In addition, the diverse embryological origin of the tongue explains its diverse sensory supply (Fig. 3).

2.3.1 Embryology

From an embryological perspective (Moore, 1977; Scott and Symons, 1971; Berkovitz, Holland, and Moxham, 1978; Du Brul, 1980; Williams and Warwick, 1980), the tongue musculature arises from the branchial apparatus. From the first branchial mandibular arch, at about the end of the fourth week of intrauterine development, a median, somewhat triangular elevation appears in the floor of the pharynx, just cranial to the foramen cecum (Figs. 2, 4A). This elevation, the tuberculum impar (median tongue bud or swelling), gives the first indication of tongue development. Soon, two oval lateral lingual swellings (distal tongue bands or swellings) develop on each side of the tuberculum impar. These three elevations result from proliferation of mesenchyme in the ventromedial parts of the first pair of branchial arches. The lateral lingual swellings rapidly increase in size, merge with each other, and overgrow the tuberculum impar. The fused lateral lingual swellings form the anterior two thirds or body of the tongue (Fig. 4C). The plane of fusion of the lateral lingual swellings is indicated superficially by the median sulcus of the tongue and internally by the fibrous median septum. The tuberculum impar forms no significant portion of the adult tongue.

The posterior third or root of the tongue is initially indicated by two elevations that develop caudal to the foramen cecum (Fig. 4A):

(1) The copula, formed by fusion of the ventromedial parts of the second branchial hyoid arches, and

(2) the large hypobranchial eminence, which develops caudal to the copula from mesoderm in the ventromedial parts of the third and fourth branchial arches. From the back of the hypobranchial eminence, the epiglottis is derived.

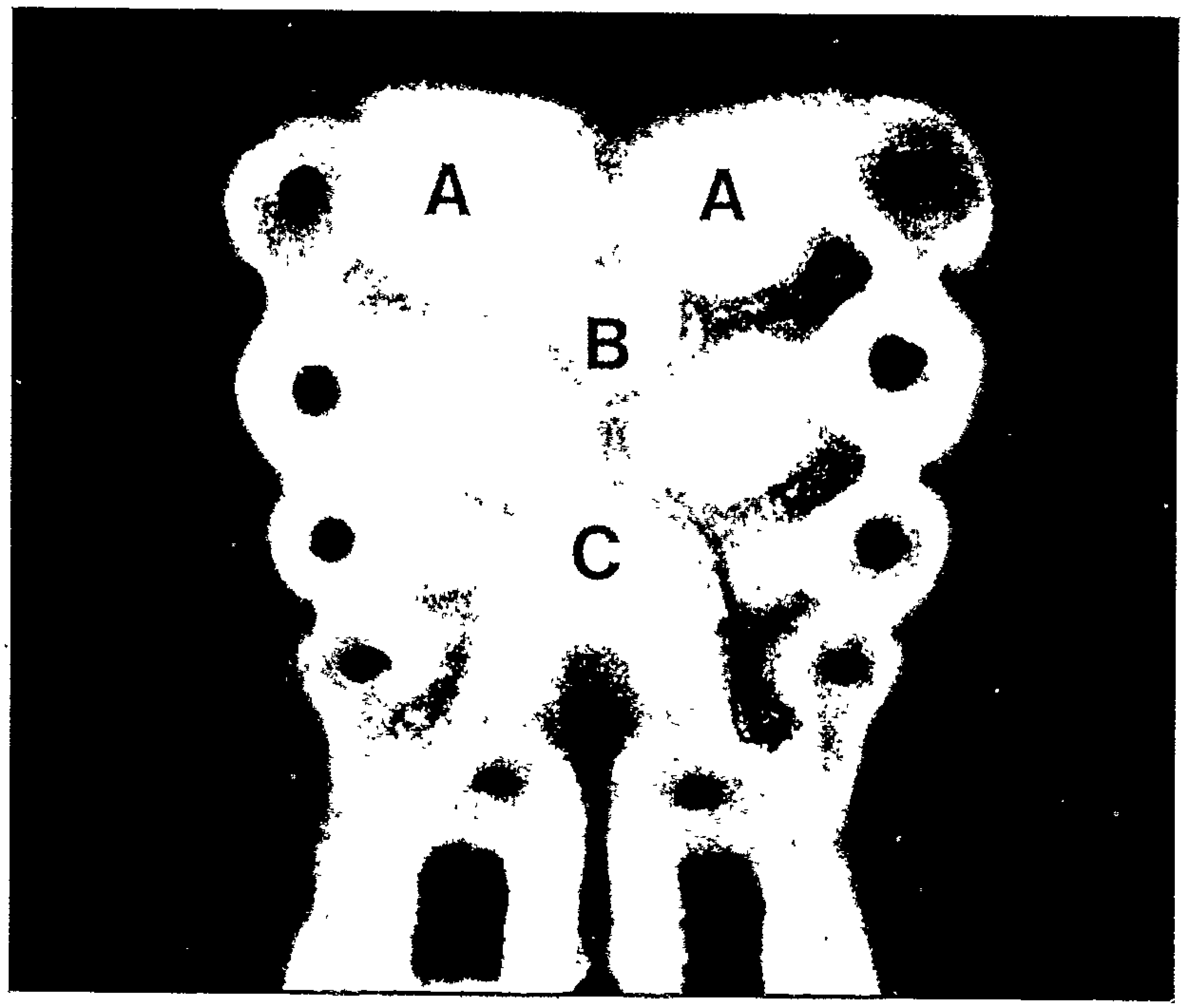


Fig. 2 Tongue primordia, 4th week intrauterine. Anterior 2/3rds: (A) lateral lingual swellings, (B) tuberculum impar. Posterior 1/3rd: (C) cupola. (Berkovitz et al., 1978)

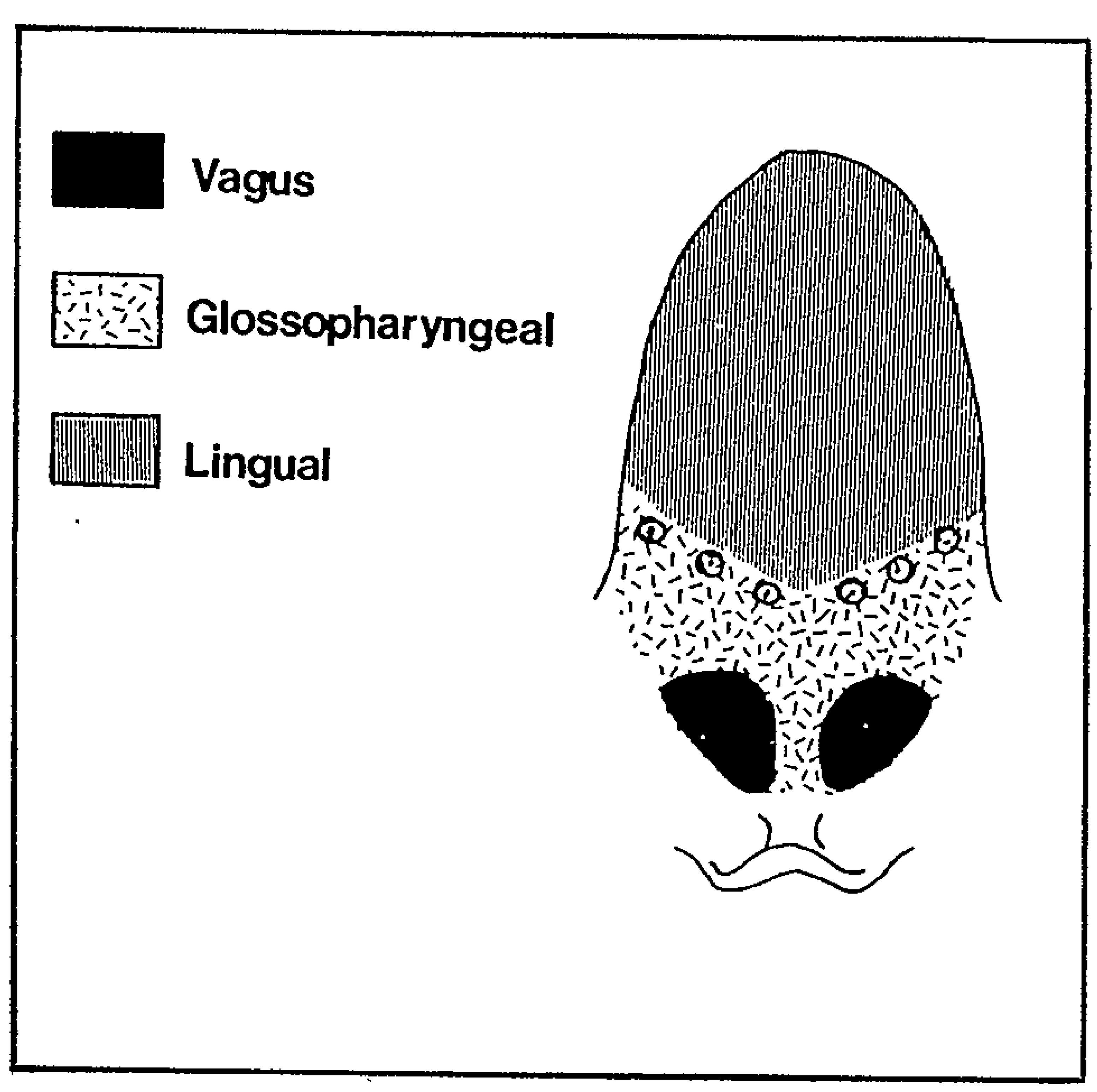


Fig. 3 Sensory innervation of the tongue - 3 distinct nerve fields. (Berkovitz et al., 1978)

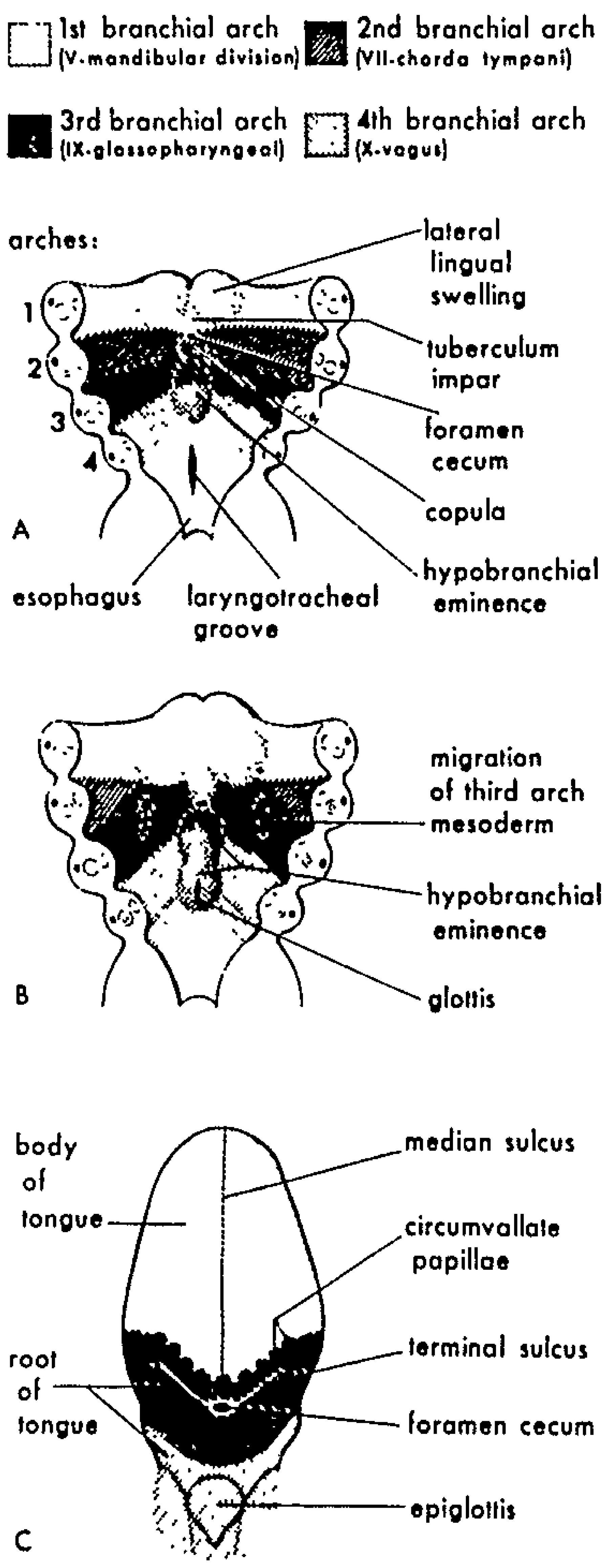


Fig. 4 A and B, successive stages in the development of the tongue during the 4th and 5th weeks.
C, adult tongue showing the branchial arch derivation of the nerve supply of the mucosa. (Moore, 1977)

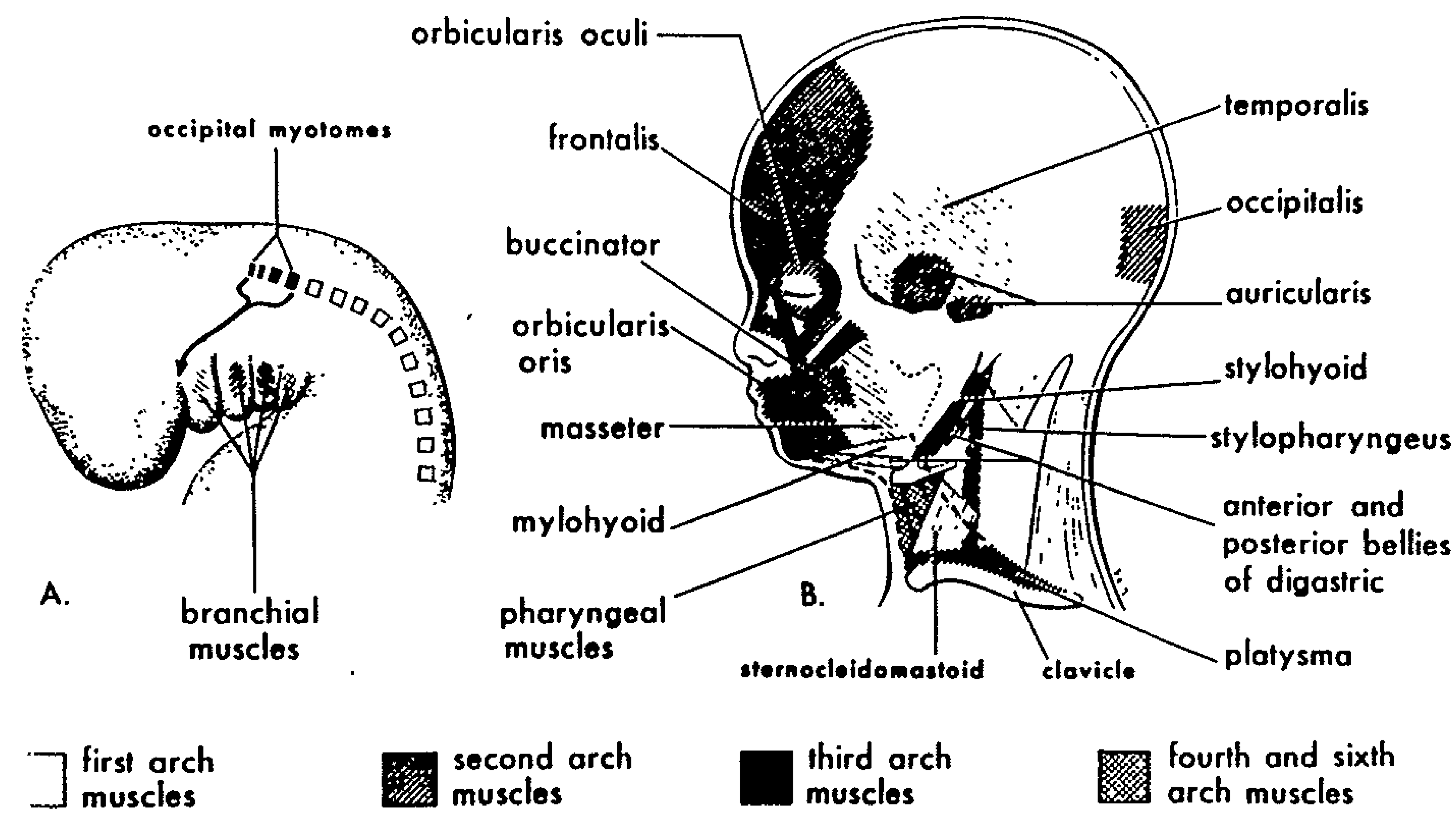


Fig. 5 A, embryo (4th week) showing the branchial muscles. The arrow shows the pathway taken by myoblasts from the occipital myotomes to form the tongue musculature.
B, Foetus (20th week) showing the muscles derived from the branchial arches. (Moore, 1977)

As the tongue develops, the copula is gradually overgrown by the hypobranchial eminence and disappears (Figs. 4B, 4C). As a result, the posterior third of the tongue develops from the cranial part of the hypobranchial eminence. The line of fusion of the anterior and posterior parts of the tongue is roughly indicated by the V-shaped groove, the terminal sulcus (Fig. 4C).

Branchial arch mesoderm forms the connective tissue, lymphatic and blood vessels of the tongue, and probably some of its muscle fibres. Most of the tongue musculature, however, is derived from myoblasts that migrate from the myotomes of the occipital somites (Fig. 5). This process starts between the sixth and eighth week of foetal life.

From another perspective, during its early development the tongue lies partly in the nasal cavities. It later descends from this position, in part as a result of the more vertically diverted growth of the mandible, and in part as a result of the opening out of the cranial base angle. The descent of the tongue permits the palatal folds to unite above its dorsum.

The studies of Bell (1970) concerning the anatomy of the tongue tip of the late foetal stage revealed more para-embryological information. He reported finding a "mature muscle architecture in the neonatal tongue tip", and close muscle insertions into the dorsal mucosa, believing this may be significant in the tongue tip's ability to perform intricate movements from an early age. This would help to explain the tongue's ability to function so well at an advanced level during the postnatal period, the advantages of this ability to the neonate's survival being obvious.

2.3.2 Lingual Musculature

The tongue has been described anatomically by numerous authors (Barrett and Hanson, 1978; Du Brul, 1980; Fried, 1976; Montgomery, 1981; McMinn and Hobdell, 1974; Pierce, 1978; Riviere, 1983; Williams and Warwick, 1980), all of whom agree on the main aspects of the tongue's description, although with minor degrees of disagreement (usually changes of emphasis on the importance of different structures). It is agreed that the tongue is a complex, powerful, muscular organ and as Fried (1976) puts it, "... with a fantastic ability to alter its shape, configuration, and position". What is it about the tongue that gives it this "fantastic ability"? To understand this a detailed description of the lingual musculature is necessary as well as a thorough, if not as detailed, account of the musculature that surrounds the tongue and participates synergetically in normal function.

As most authors would put it, the tongue is covered by mucous membrane, and, other than its covering, is composed almost entirely of muscles. Nerves and blood vessels go to make up the rest of its composition. Simplistically, the blood supply is mainly via the lingual artery, the nerve supply is by way of the hypoglossal nerve. The neurophysiology is described in a later section.

The tongue lies partly in the mouth, and partly in the pharynx (Fig. 6). It is attached by its muscles to the hyoid bone, the mandible, the styloid processes, the soft palate, and the wall of the pharynx. The tongue's main parts (Figs. 7, 8) are the root, tip, dorsum, and inferior surface. The root attaches the organ to the hyoid bone and the mandible. The main vessels and nerves enter through this part. The tip is the most anterior and most mobile part, and merges into the inferior surface. The dorsum or upper surface constitutes about two-thirds of the superficial or superior surface, the

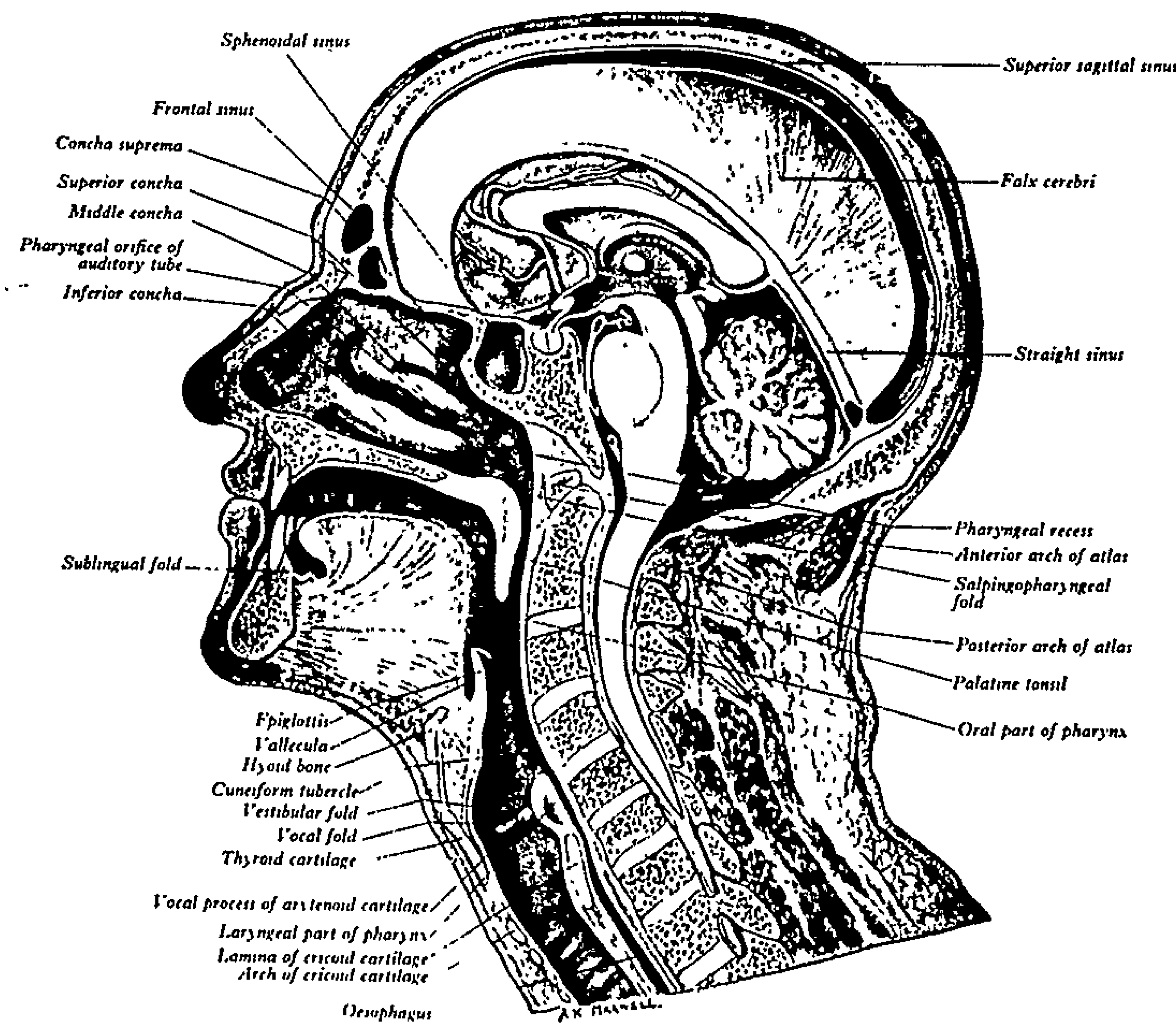


Fig. 6 Median sagittal section through the head and neck. (Williams and Warwick, 1980)

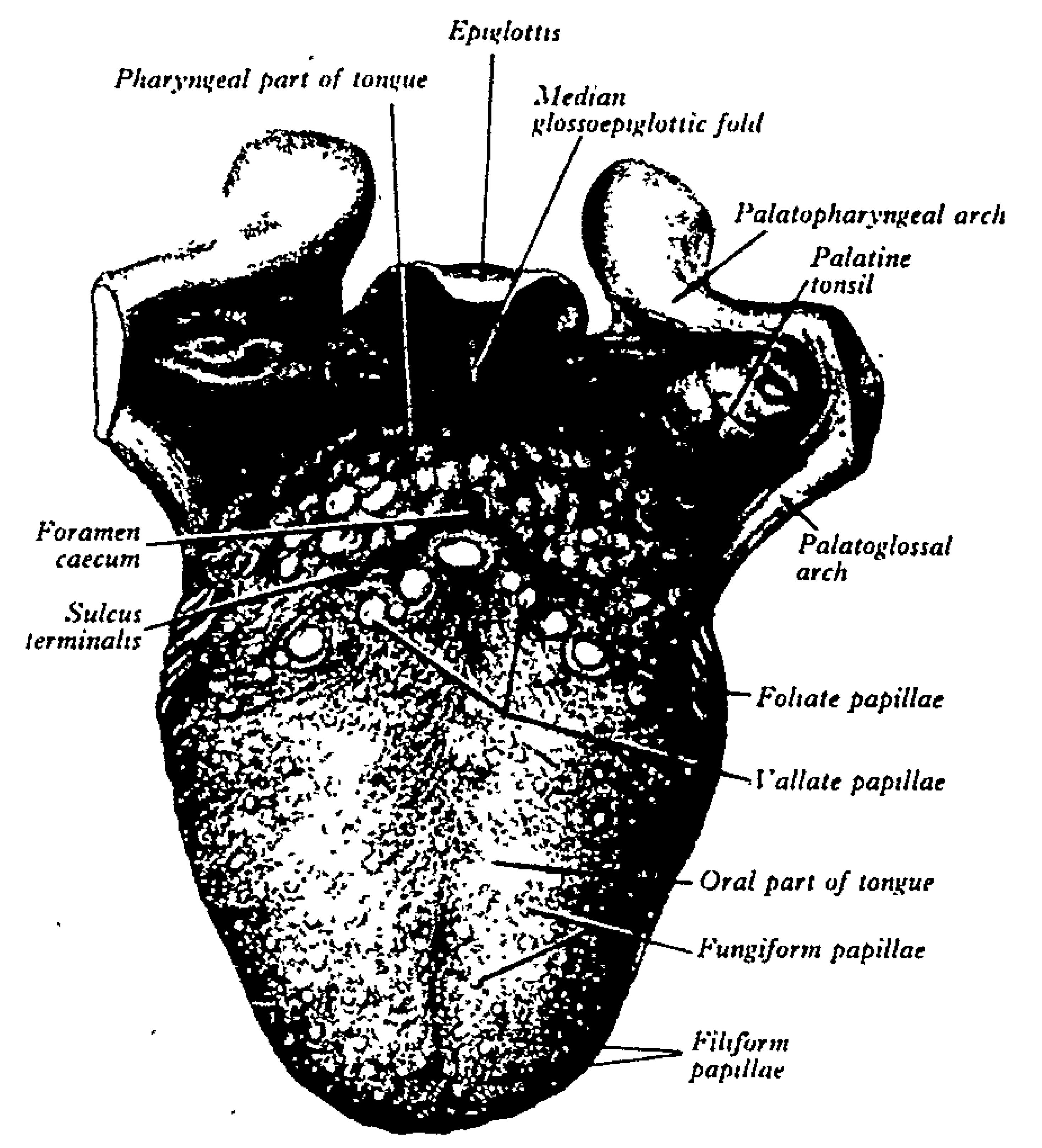


Fig. 7 Dorsum of the tongue. (Williams and Warwick, 1980)

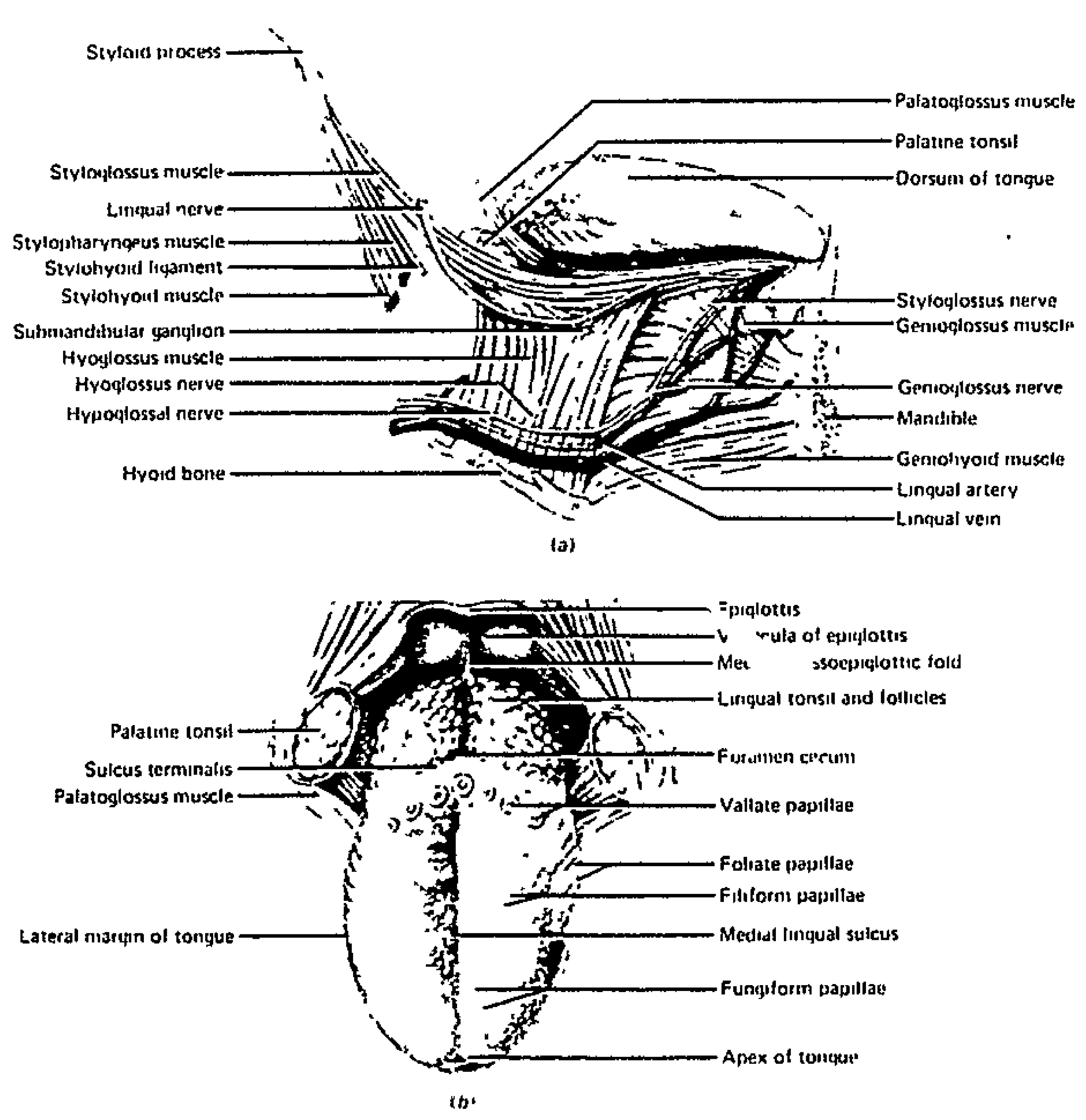


Fig. 8 Lateral and dorsal views of the tongue. (Montgomery, 1981)

remaining third facing posteriorly, termed the "base" by McMinn and Hobdell (1974). These two parts are separated by a V-shaped furrow, the sulcus terminalis, the limbs of which run laterally and forwards from a median pit, the foramen cecum, to the palatoglossal arches. The margins of the tongue meet anteriorly at the apex. On each border of the superior or dorsal surface are the foliate papillae; these are four or five vertical folds just in front of the palatoglossal arches. The dorsum of the tongue has a characteristically rough appearance due to the presence of dorsal lingual papillae (Fig. 8). These lie on the anterior two-thirds of this surface. There is some confusion among the authors as to how many types of papillae there are. Most (Montgomery, 1981; Du Brul, 1980; Williams and Warwick, 1980) describe the three main types other than the foliate papillae. These are: the vallate papillae, the filiform papillae, and the fungiform papillae, moving from posterior to anterior. Williams and Warwick (1980) describe another group, the "papillae simplices", which are said to cover the whole of the mucous membrane of the tongue as well as the large papillae. Montgomery (1981) alludes to "intermediate forms" of papillae that occur between the other papillae. While Du Brul (1980) regards one of the four types of papillae as being vestigial in man, it could be interpreted that they are referring to the foliate papillae. Briefly, the papillae are covered by taste buds, and are designed to increase the surface area of mucous membrane coming into contact with the fluid which is being tasted.

The posterior surface of the dorsum, or the pharyngeal surface of the tongue (Fig. 9), lies behind the palatoglossal arches and posterior to the terminal sulcus. It is studded with oval or rounded, low prominences separated from each other by irregular, shallow furrows. The prominences are called "lingual follicles" and are caused by the accumulation of lymphatic tissue. Collectively they constitute the lingual tonsil.

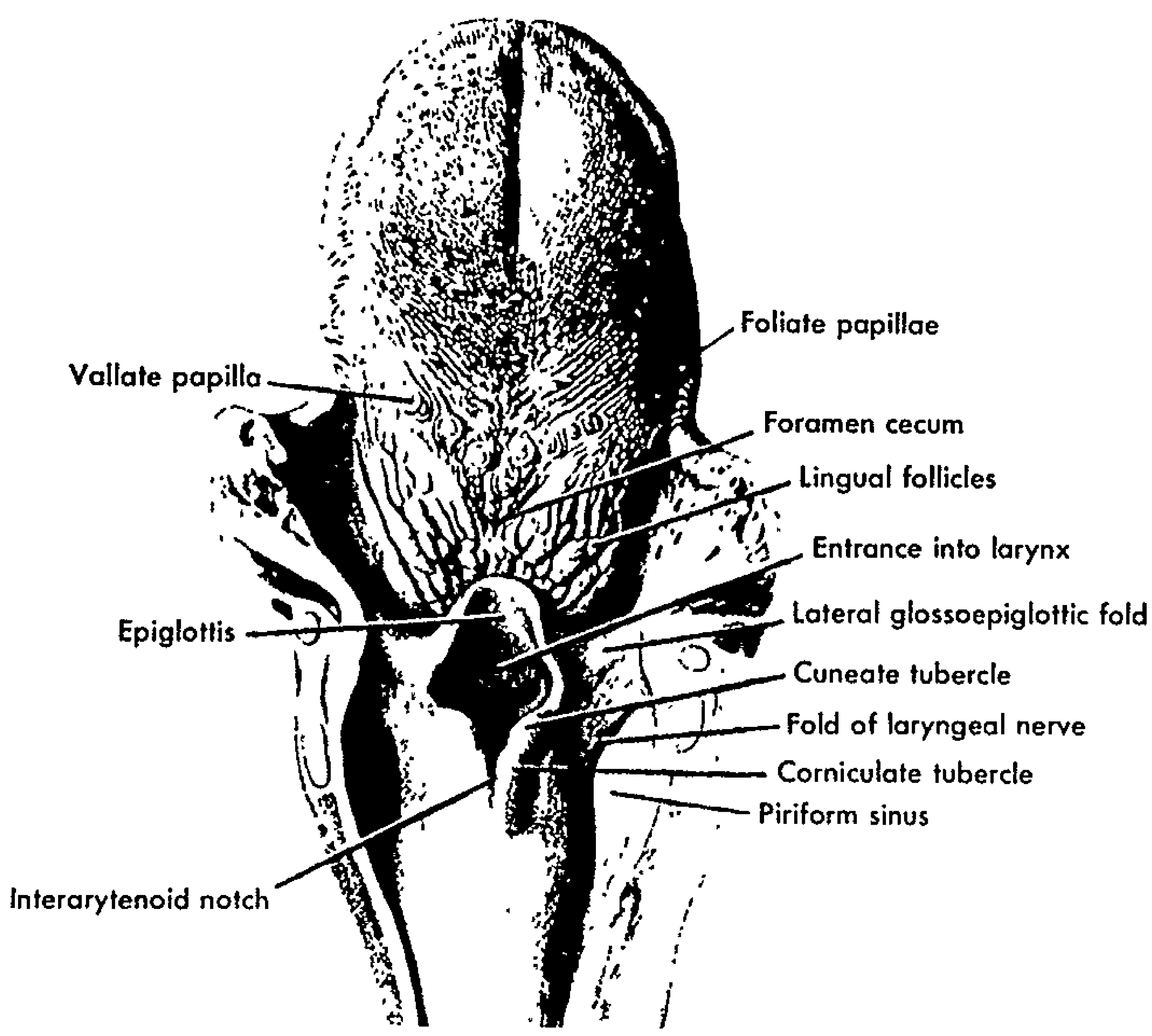


Fig. 9 Tongue and entrance into larynx. (DuBrul, 1980)

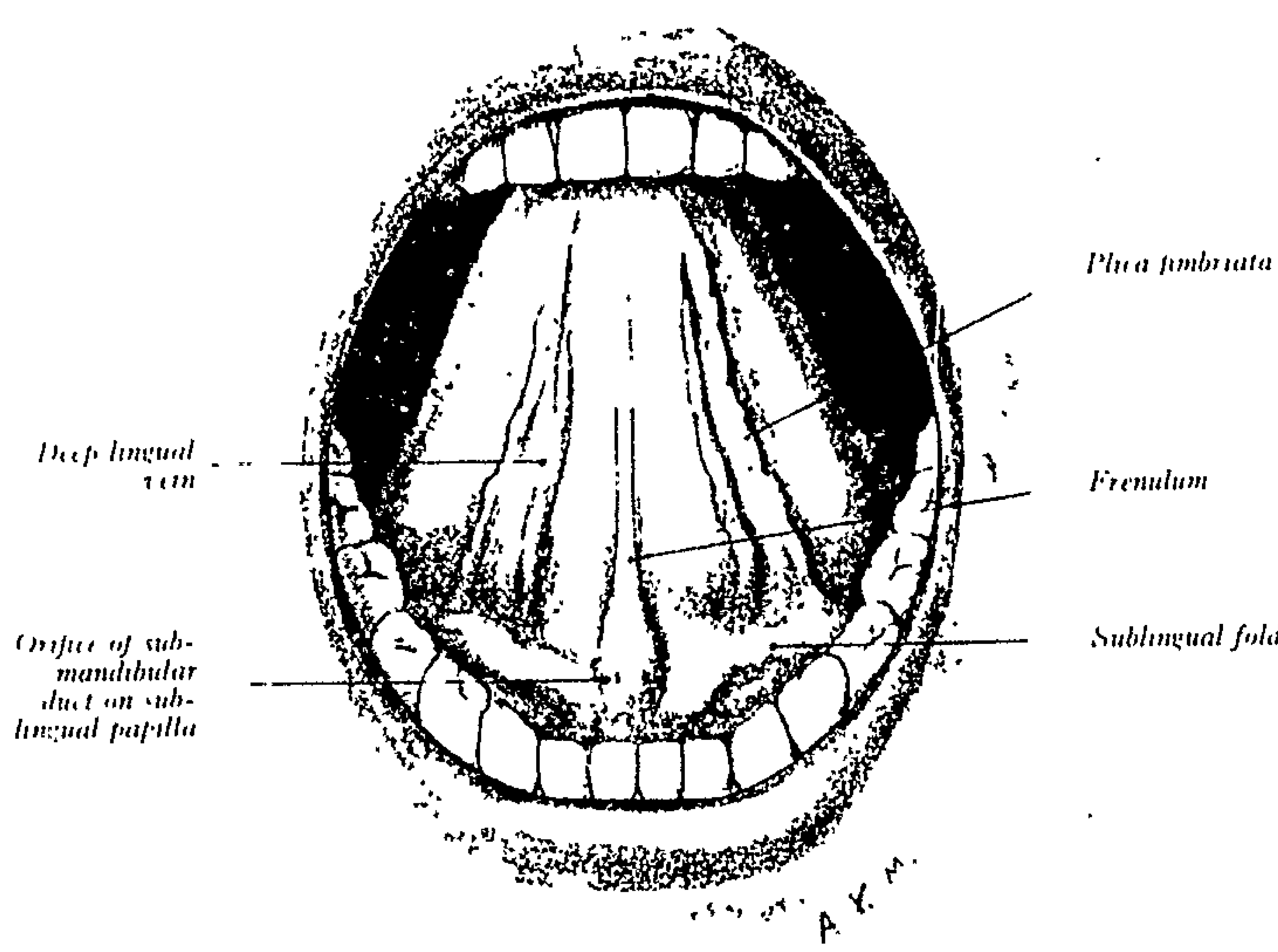


Fig. 10 Oral cavity with tongue raised. (Williams and Warwick, 1980)

At this region the dorsum, facing the pharynx, merges with the root of the tongue (Figs. 7-9). The root is connected with the palate by the palatoglossal arches, being continuous with the region of the palatine tonsils. It is connected with the epiglottis by the median glossoepiglottic fold. On either side of this sickle-shaped fold are variably deep depressions, the epiglottic valleculae. They are bounded laterally by the lateral glosso-epiglottic folds. Of note is the fact that the terminal sulcus forms a fairly sharp boundary between the lymphoid mucosa of the root and the papillated mucosa of the body of the tongue.

The inferior surface of the tongue is chiefly related to the floor of the mouth and is associated with muscles from the hyoid bone and the mandible, as well as the salivary glands. Anteriorly and laterally, the inferior surface is free and covered with mucosa, without papillae, that continues across the sublingual region. In the median plane is a prominent fold, the lingual frenulum or frenum, which connects the tongue with the mandible and the floor of the mouth (Figs. 10,11). On each side of the inferior surface is an irregular fold, the fimbriate fold or plica fimbriata. Between the frenum and the fimbriate folds the lingual veins are visible on each side beneath the mucosa. The openings of the submandibular ducts are found at the base of the tongue on either side of the midline where the lingual frenum joins the mucous membrane covering the floor of the mouth. Also found in this region are the sublingual folds along which are many small duct openings from mucous glands, the largest being the sublingual gland.

The tongue is divided into lateral halves by a median fibrous septum that extends the entire length of the tongue and is fixed to the hyoid bone below. This division is outlined on the surface; inferiorly by the lingual frenum, and superiorly by the midline groove running from anterior to posterior

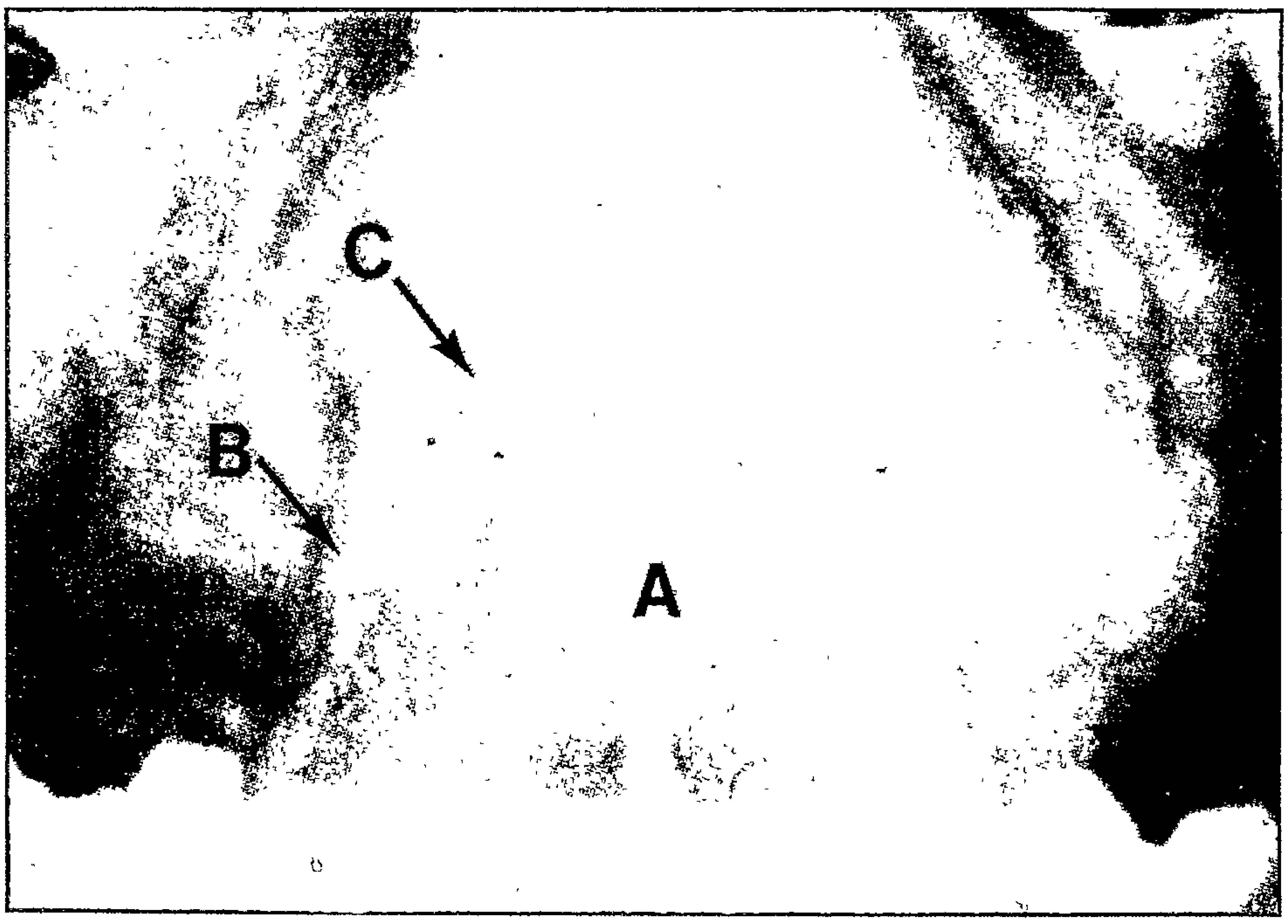


Fig. 11 Inferior surface of the tongue. A, lingual frenum. B, fimbriated folds. C, sublingual veins. (Berkovitz et al., 1978)

on the dorsum of most tongues. All lingual muscles are paired this way. Since there are eight constituent muscles of the tongue, each half of the tongue will have a full set of eight. The lingual septum then separates the muscles of the tongue into right and left pairs.

The pairs of muscles on each side of the septum are four intrinsic muscles and four extrinsic muscles. The intrinsic muscles lie entirely within the tongue itself, and are responsible for changes in the shape of the tongue. The extrinsic muscles originate at a point distant from the tongue and insert on, and interlace with, intrinsic muscles. The extrinsic muscles are accountable for most movements of the tongue.

2.3.2.1 Intrinsic Muscles of the Tongue (Figs. 12-16)

The intrinsic muscles can be subdivided into superior and inferior longitudinal, transverse, and vertical. They are named for their planes of direction within the tongue and although there is considerable interweaving of fibres, they remain to a great degree separate bundles or layers. Fibres from the extrinsic muscles also blend in, providing the tongue with the potential for infinite versatility, while maintaining firm coordination between the position and shape of the tongue. The varying shapes that the tongue can assume are quite complex but can be predicted once one considers what happens when the various intrinsic fibres contract.

Superior Longitudinal Muscles: The superior longitudinal muscle fibres lie in a thin layer directly under the dorsal mucosa. They arise from the posterior submucous fibrous tissue and run forward and obliquely to insert on the edges of the tongue.

Inferior Longitudinal Muscles: The inferior longitudinal muscle fibres

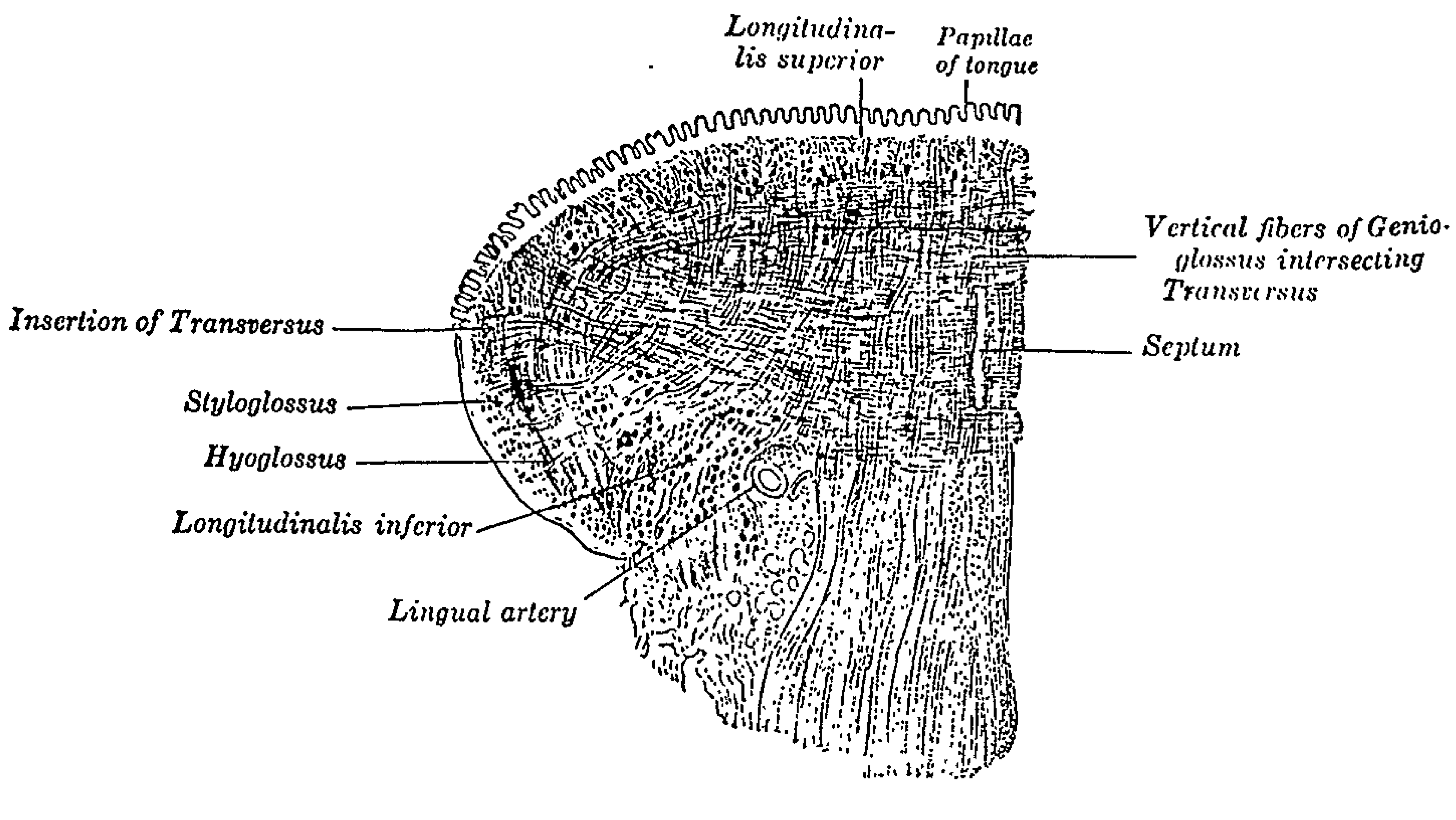


Fig. 12 Intrinsic tongue muscles - coronal section. (Fried, 1976)

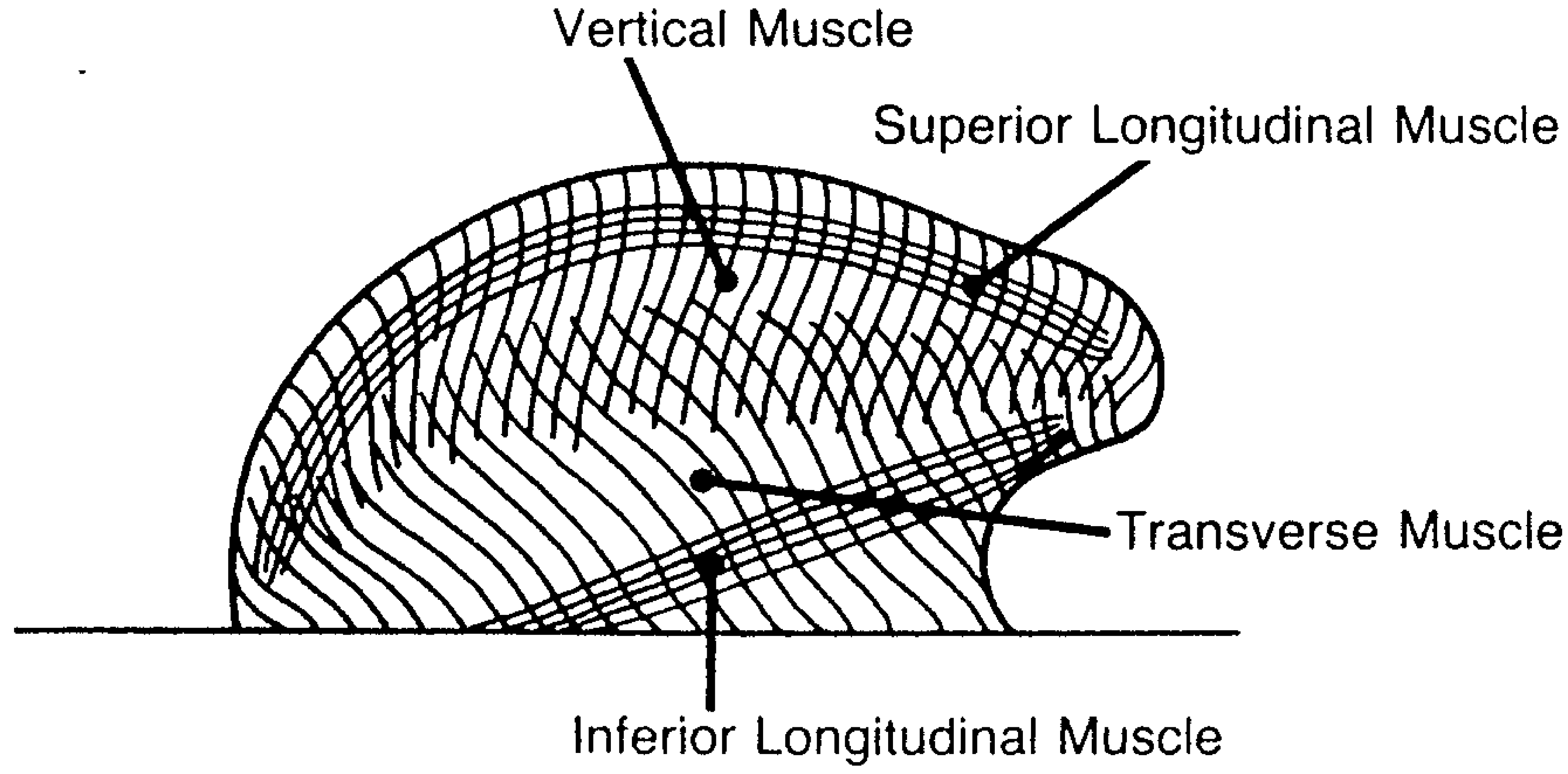


Fig. 13 Intrinsic tongue muscles - sagittal section. (Pierce, 1978)

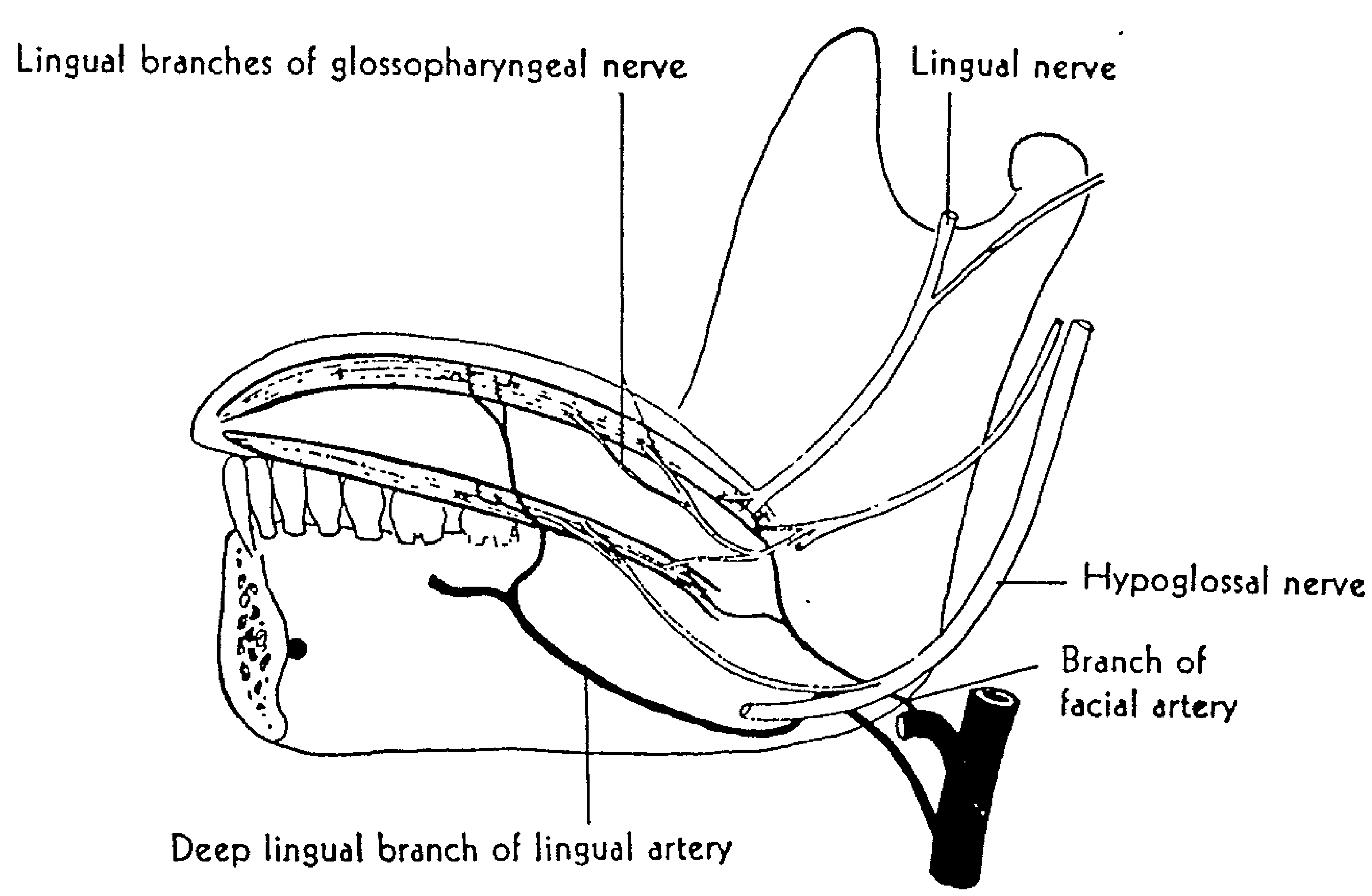


Fig. 14 Superior and inferior longitudinal muscles. (Fried, 1976)

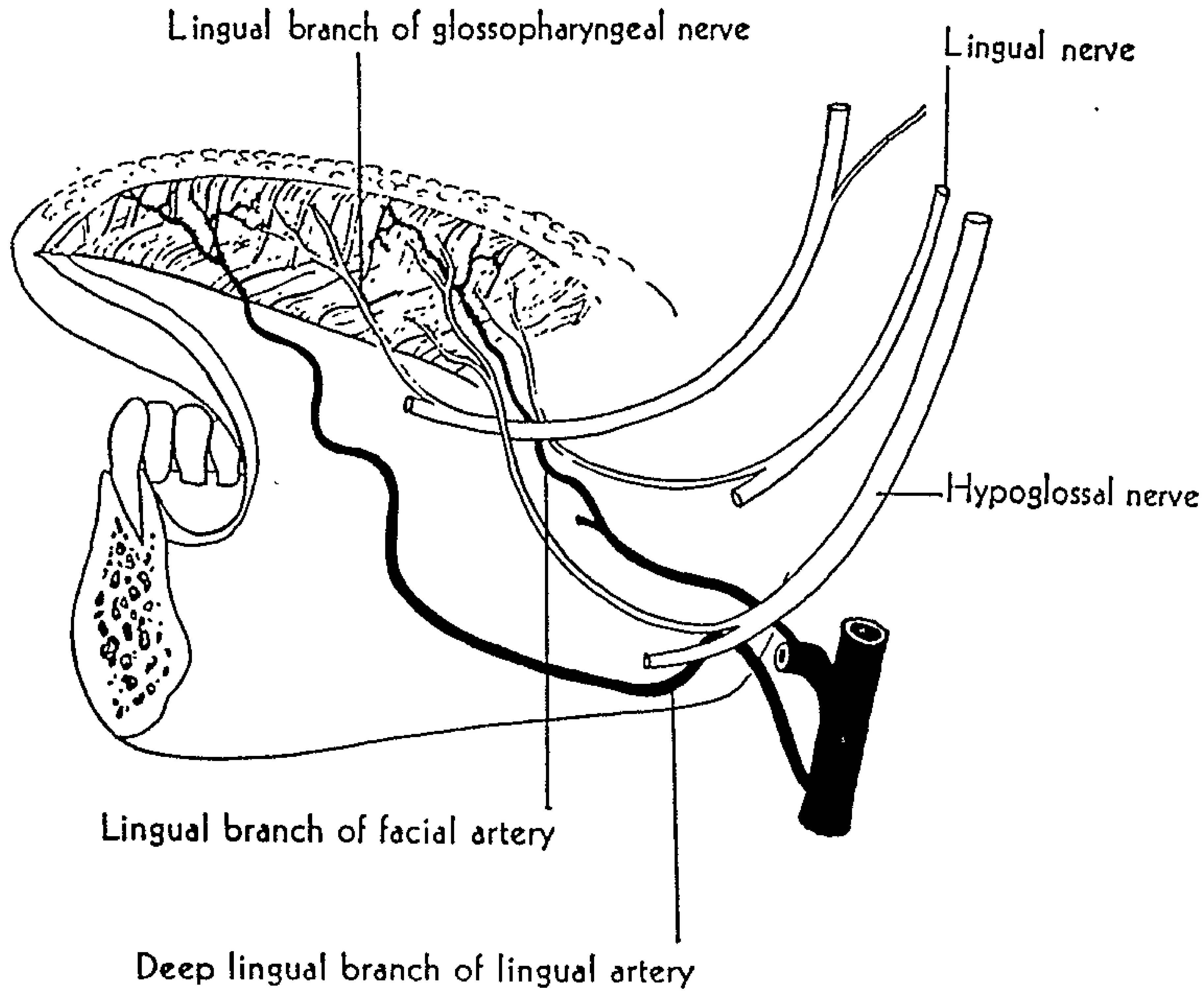


Fig. 15 Transverse and vertical fibres. (Fried, 1976)

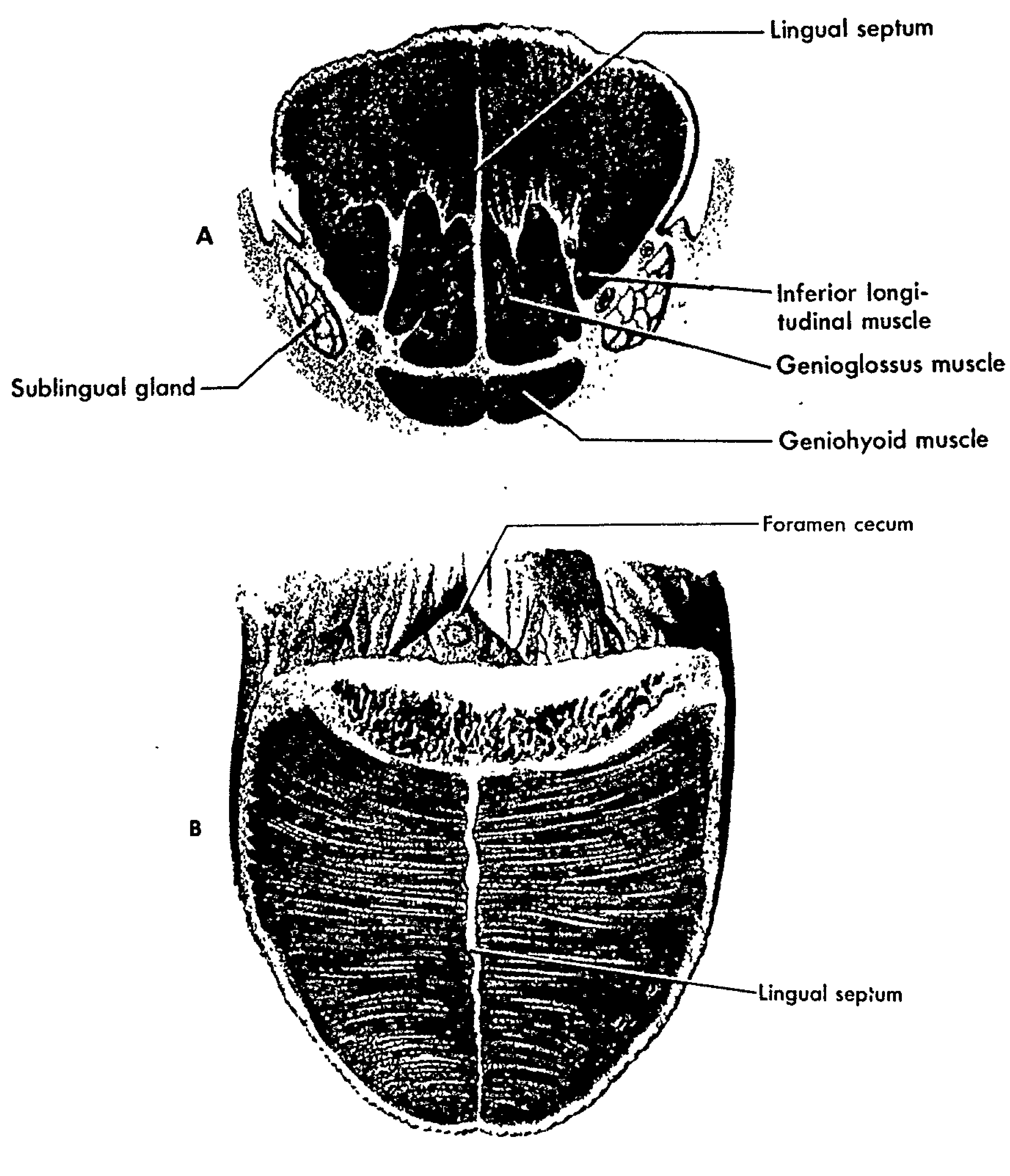


Fig. 16 A, cross-section through tongue.
B, horizontal section: lingual septum and transverse muscles.
(DuBrul, 1980)

form narrow bands situated on the undersurface of the tongue and extend from the root to the apex. They lie between the genioglossus and hyoglossus muscles. Some of the fibres near the apex mix with those of the styloglossus, while dorsally some are attached to the hyoid bone.

Transverse Muscles: The transverse muscle fibres originate on the median septum and pass laterally to the lateral borders of the tongue. These muscles are situated between the superior and inferior longitudinal muscles.

Vertical Muscles: The vertical muscle fibres are found in the forepart of the tongue and extend from the upper to the undersurface. These fibres interlace with those of the other intrinsic and extrinsic muscles. The fibres of the vertical and transverse muscles decussate (see Fig. 17 for a summary and further functional information).

2.3.2.2 Extrinsic Muscles of the Tongue (Figs. 18-21)

The extrinsic muscles are the genioglossus, hyoglossus, styloglossus, and palatoglossus. The chondroglossus (Williams and Warwick, 1980) is included in the description of the hyoglossus by most authors, and the palatoglossus is often regarded more as a soft palate muscle. However, as the name implies, it is still an extrinsic muscle of the tongue.

These muscles greatly increase the mobility of the tongue and also serve to integrate the movements of the tongue with those of the soft palate and pharynx during swallowing and speech.

Genioglossus: This muscle is the strongest of the extrinsic muscles of the tongue. It is a flat, triangular muscle arising from the superior genial tubercles of the mandible. The more anterior/superior fibre bundles radiate toward the tip of the tongue; the intermediate bundles extend directly toward

Intrinsic muscles of the tongue*

Muscle	*Origin*	*Insertion*	*Function*
Superior longitudinal	Submucosa near epiglottis; median septum of tongue	Edges of tongue	Shortens, widens tongue; turns tip and sides up, forming concave dorsum
Inferior longitudinal	Lower portion of root of tongue	Apex (tip) of tongue	Shortens, widens tongue; depresses tip, forming convex dorsum
Transverse	Median septum of tongue	Mucosa at side of tongue	Narrows, elongates tongue
Vertical	Upper surface of tongue	Lower surface of tongue	Flattens, widens tongue tip

*All innervated by cranial nerve XII.

Fig. 17 Table: Intrinsic muscles of the tongue. (Barrett and Hanson, 1978)

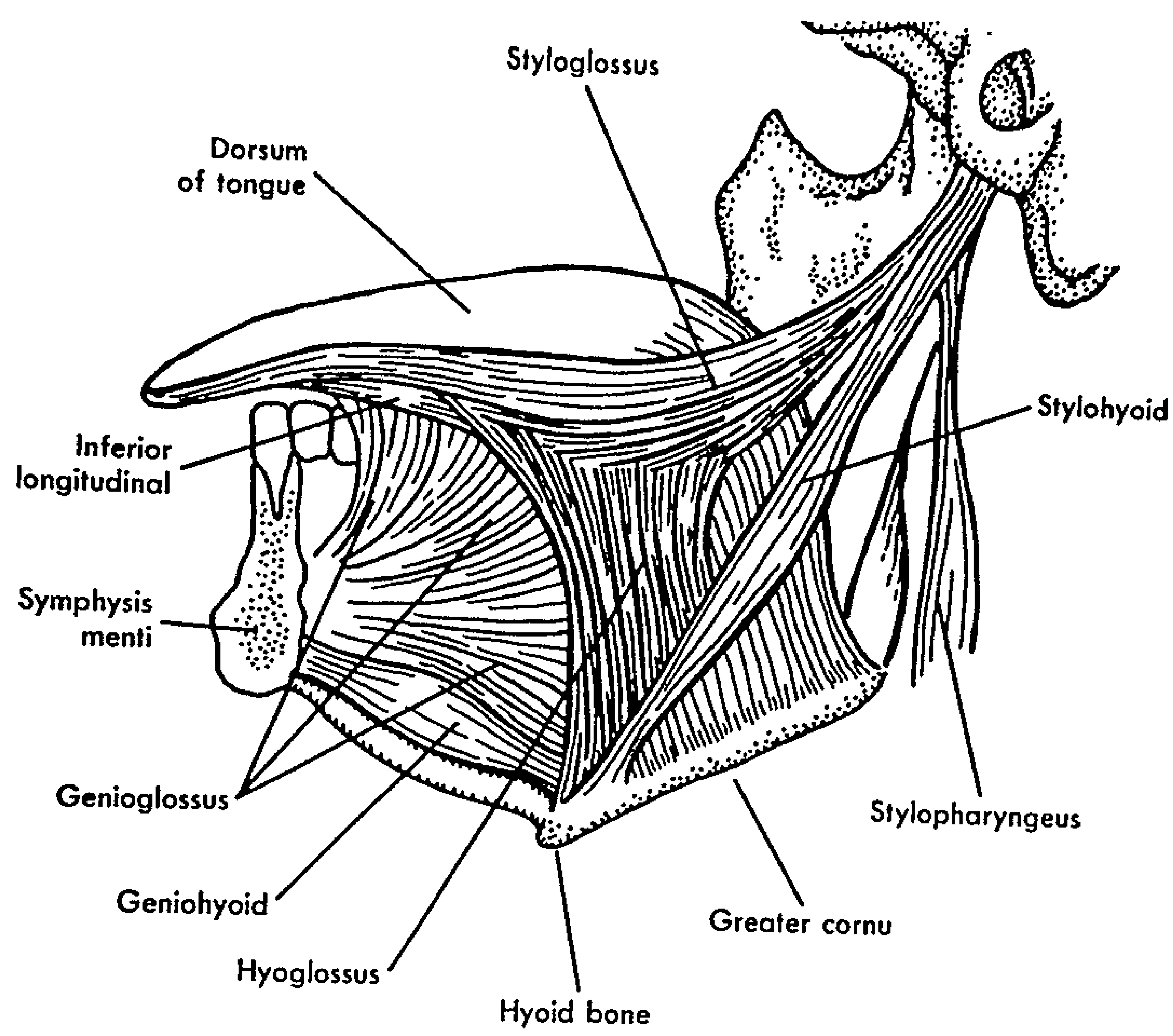


Fig. 18 Extrinsic muscles of the tongue. (Barrett and Hanson, 1978)

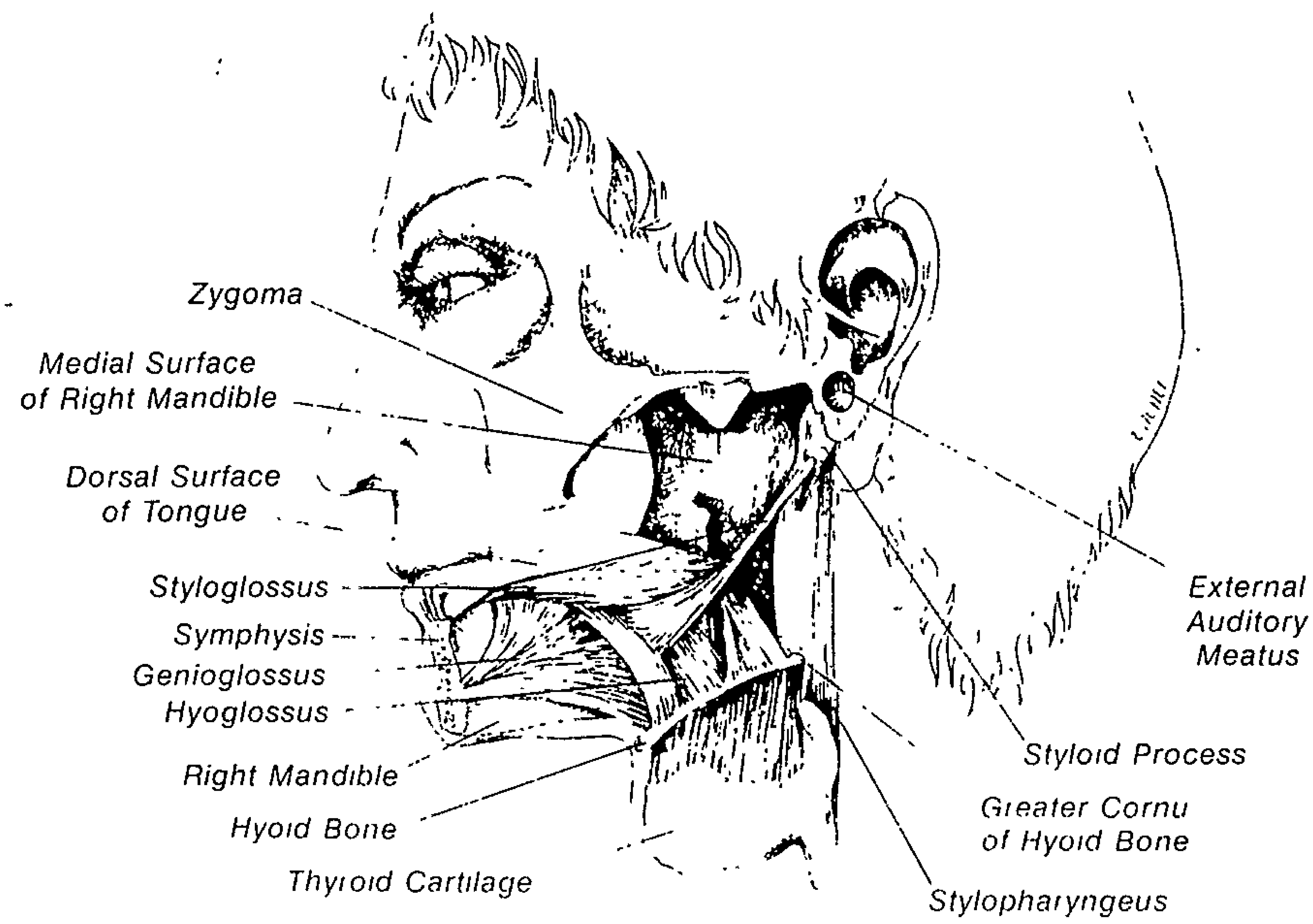


Fig. 19 Extrinsic tongue muscles with associated structures. (Fried, 1976)

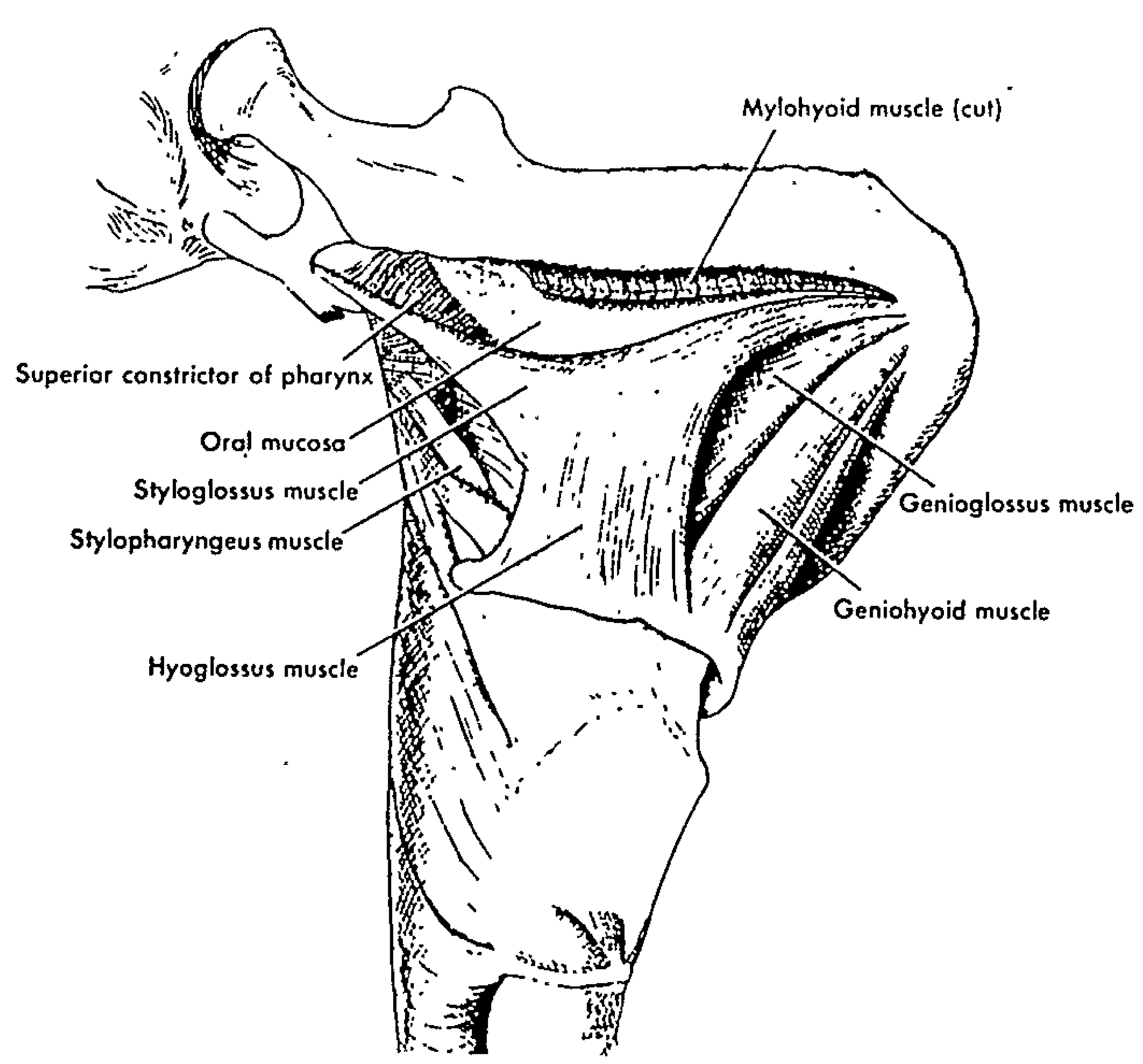


Fig. 20 Extrinsic tongue muscles: inferior view. (DuBrul, 1980)

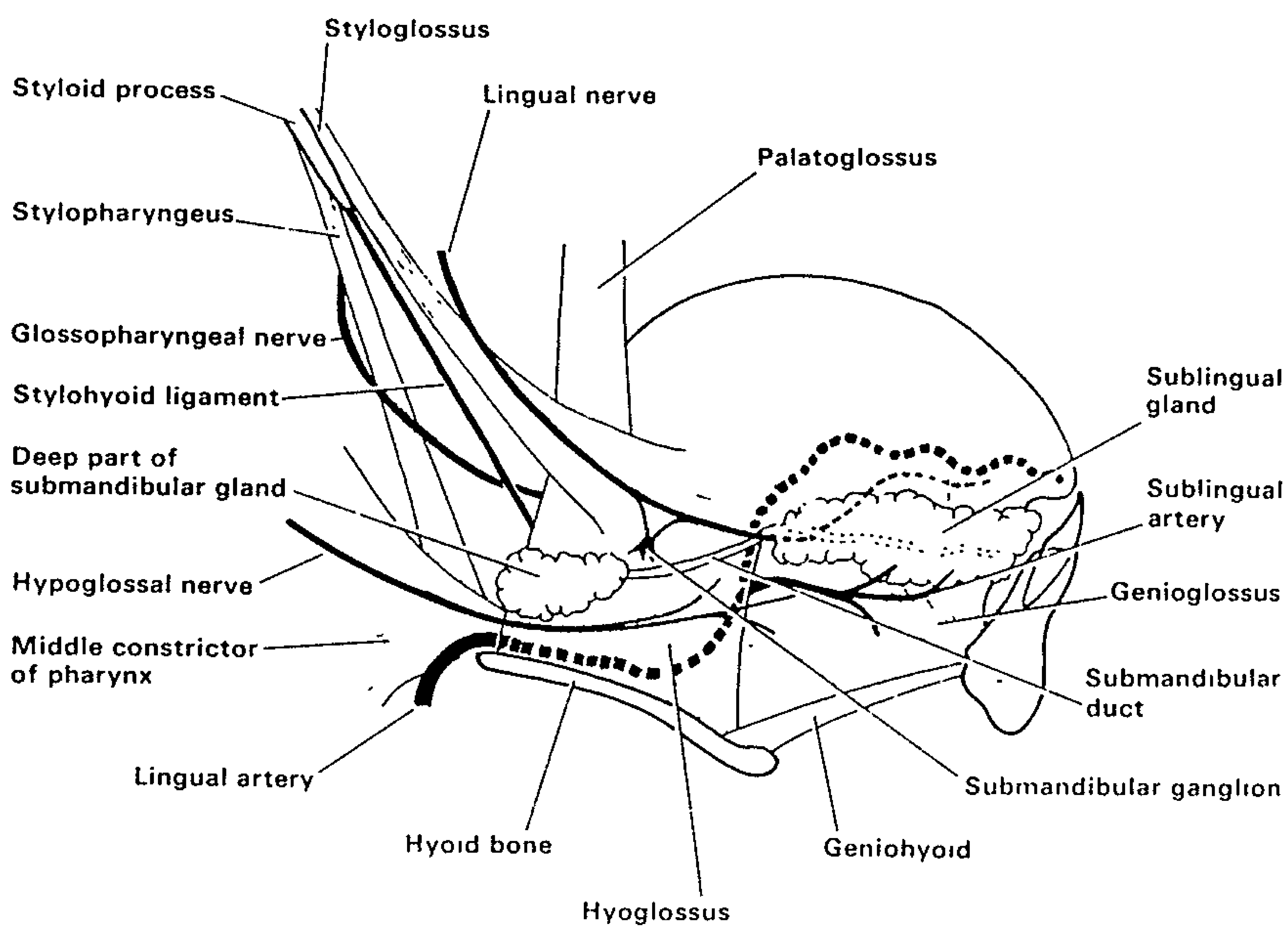


Fig. 21 Extrinsic muscles. Hyoglossus (posterior border) - glossopharyngeal nerve, stylohyoid ligament, lingual artery, lingual nerve, submandibular duct, and hypoglossal nerve. (McMinn and Hobdell, 1974)

the dorsum of the tongue, where they are inserted into the lingual fascia; and the inferior bundles curve back to be inserted into the medial part of the superior border of the hyoid bone.

The anterior/superior fibres withdraw and depress the tip of the tongue. They also work in concert with the intermediate fibres to draw the entire dorsum of the tongue downward into a concave channel, as in sucking action. The intermediate fibres alone draw the base of the tongue forward and thereby protrude it. The inferior fibres pull the hyoid bone upward and forward, a part of the synergy of actions involved as the entire larynx moves up and forward during deglutition. This muscle not only constitutes a large physical proportion of the tongue, it does most of the work. It also poses, according to Barrett and Hanson (1978) one of the major challenges for the clinician, since lack of a normal balance of tonus, e.g. neural deficit, among the three segments of the genioglossal fibres allows the tongue to drift forward and downward to a "familiar but undesirable" interdental resting posture (see section 4.4.7).

Hyoglossus: The hyoglossus muscle originates from the greater horn and body of the hyoid bone. It is a thin rectangular sheet of muscle. It passes vertically upward and enters the side of the tongue, between the stylo-glossus laterally and the inferior longitudinal medially; interlacing of fibres occurs as the hyoglossus passes these muscles. It then passes medially to insert into the medial septum of the tongue, while its fibres again intermingle with other intrinsic muscle fibres. The bundles of the hyoglossus muscle which arise from the lesser hyoid horn are sometimes referred to as the 'chondro-glossus' muscle. These fibres ascend and blend with the intrinsic muscles of the tongue. Williams and Warwick (1980) describe these muscle fibres as being separated from the hyoglossus by the genioglossus. Riviere (1983) describes the insertion of the hyoglossus into the side of the tongue dividing into two heads.

The contraction of the hyoglossus pulls the tongue down and back, and when the hyoid is fixed, it depresses the sides of the tongue.

Styloglossus: The styloglossus originates from the styloid process of the temporal bone. It passes downward and forward to the side of the tongue, and divides into two segments, the longitudinal and oblique portions. The longitudinal segment enters the side of the tongue near its dorsal surface, at about the base of the palatoglossal arch, where the palatoglossus divides its fibres into an upper and a lower bundle. After blending with the fibres of the inferior longitudinal muscle the longitudinal segment runs to the tip of the tongue. The oblique segment overlaps and penetrates the hyoglossus muscle as it runs transversely to the midline of the tongue. As it penetrates the hyoglossus, the oblique fibres decussate with the hyoglossus fibres.

Contraction of the styloglossus causes the tongue to move upwards and backwards, the body of the tongue being retracted while the sides are drawn upwards.

Palatoglossus: As previously mentioned, the palatoglossus is regarded by most authors as a soft palate muscle since it is more closely associated with the soft palate in situation, function, and nerve supply. The palatoglossus extends from the undersurface of the soft palate to form the anterior tonsillar pillar. It then inserts into the dorsum and side of the tongue. Since both ends attach to mobile structures, its contraction may either draw the sides of the tongue up and back, or draw down the sides of the velum or soft palate, depending upon which end of the muscle is more firmly fixed at that moment.

2.3.2.3 Nerve Supply of Tongue Muscles

Motor: All the intrinsic muscles are innervated by the twelfth cranial nerve, the Hypoglossal nerve.

The Hypoglossal nerve also supplies all the extrinsic muscles with the exception of the palatoglossus.

The nerve supply to the palatoglossus muscle is via the pharyngeal plexus, although the authors differ as to which cranial nerve is responsible. Williams and Warwick (1980) say it is the Accessory or eleventh cranial nerve, while Barrett and Hanson (1978) and Riviere (1983) say it is the Vagus or tenth cranial nerve. Du Brul (1980) does not commit himself, saying it is supplied by "the pharyngeal plexus of nerves", which is probably the most realistic description.

Sensory: The sensory nerve supply is included so that a complete view of the nervous structure of the tongue can be appreciated. Three cranial nerves (Barrett and Hanson, 1978) have sensory receptors in the lingual structures; they are: Trigeminal (V), mandibular branch; Facial (VII); and Glossopharyngeal (IX).

Trigeminal - mandibular branch: receives pain, touch and temperature sensations from the anterior part of the tongue.

Facial: is responsible for taste in the anterior two-thirds of the tongue.

Glossopharyngeal: is responsible for taste in the posterior third of the tongue as well as general sensation from the posterior part of the tongue.

A most important aspect of the neurology of the tongue, as will be discussed more fully in a later section, has been highlighted by Barrett and Hanson (1978). It is that in all the cranial nerves with mixed function, i.e. sensory and motor, fibres of the sensory and motor branches within each nerve have interconnections at subcortical levels, making reflexive action possible. Those nerves with mixed function are the Trigeminal, Facial, Glossopharyngeal, and Vagus - the very nerves just discussed in relation to the motor and sensory innervation of the tongue. The importance of this reflexive action will be discussed later.

A full description of the anatomy and pertinent neural aspects of the tongue has been presented in order to show the complexity of the workings of the lingual musculature. The scope of the investigation of the musculature now broadens to include the muscles surrounding the tongue so that its place in a functional milieu can be understood. Only the relevant musculature of the facial, oral, and pharyngeal systems will be discussed and their relationships to the swallowing process in particular.

Muscles of the Soft Palate (Velum) and the Pharynx

Unfortunately, there is very little uniformity in the way various authors (Barrett and Hanson, 1978; Berkovitz, Holland, and Moxham, 1978; Du Brul, 1980; Fried, 1976; Montgomery, 1981; McMinn and Hobdell, 1974; Pierce, 1978; Riviere, 1983; Williams and Warwick, 1980) categorise the muscles of these closely related regions. Some muscles, the palatoglossus and palatopharyngeus for example, are interchanged in grouping from soft palate to pharynx depending on the author. Their nerve supplies are also described differently from author to author. For the sake of clarity, the description of these muscles is presented in the following way.

2.3.3 Soft Palate Musculature (Figs. 22-29)

Tensor Veli Palatini (Fig. 25): This is a small muscle originating from the base of the medial pterygoid plate, the lateral wall of the auditory tube, and the spine of the sphenoid bone. It passes vertically, winds around the pterygoid hamulus, and then passes horizontally into the soft palate. It tenses the soft palate and opens the auditory tube during swallowing. According to Williams and Warwick (1980) this muscle is active in deglutition rather than in speech, and by producing a localised depression of the anterior part of the palate squeezes the bolus against the tongue and so helps its descent in the oral pharynx.

The nerve supply is via the third division of the Trigeminal nerve.

Levator Veli Palatini (Fig. 27): Arising from the petrous portion of the temporal bone and the auditory tube, this is a round band of muscle. It extends inferiorly and medially into the soft palate and joins the muscle fibres on the opposite side. It acts to elevate the vertical posterior part of the soft palate. Together with the tensor veli palatini it closes the oro- from the naso-pharynx, although it has no functional effect on the auditory tube. According to Mulder (1976) the valve-like action of the soft palate is largely controlled by this muscle. This is of special significance in relation to speech. The levator veli palatini is the leading muscle in control of the velopharyngeal mechanism in speech.

The nerve supply is via the pharyngeal plexus.

Musculus Uvulae: The unpaired uvulae muscle originates on the posterior nasal spine and palatine aponeurosis. This aponeurosis is a thin, firm, fibrous plate that supports and gives strength to the soft palate. The fibres of the uvulae muscle pass posteriorly to the mucous membrane of the uvula, and act to shorten it.

Muscles of the soft palate

Muscle	*Cranial nerve*	*Origin*	*Insertion*	*Function*
Uvula	X	Posterior nasal spine; palatal aponeurosis	Body of uvula	Elevates uvula
Tensor veli palatini	V (mandibular branch)	Scaphoid fossa; spine of medial pterygoid plate; posterior border of hard palate	Palatal aponeurosis; cartilage of eustachian tube	Tenses velum; opens eustachian tube during deglutition
Levator veli palatini	X	Lower surface, petrous portion of temporal bone; side of eustachian tube	Throughout velum to midline	Elevates velum toward posterior pharyngeal wall; dilates orifice of eustachian tube
Palatopharyngius	X	Lower: mucous membrane along posterior border of velum Upper: midline of velum	Posterior thyroid cartilage; aponeurosis of pharynx	Depresses velum; constricts faucial isthmus; elevates pharynx
Palatoglossus (see also: "Extrinsic muscle of tongue")	X	Anterior surface of velum	Side of posterior tongue	Constricts faucial isthmus; elevates tongue
Velopharyngeal sphincter	X	Midline of velum	Posterior median raphe of pharynx	Aids in moving velum posteriorly; creates ridge on posterior pharyngeal wall

Fig. 22 Table: Muscles of the soft palate. (Barrett and Hanson, 1978)

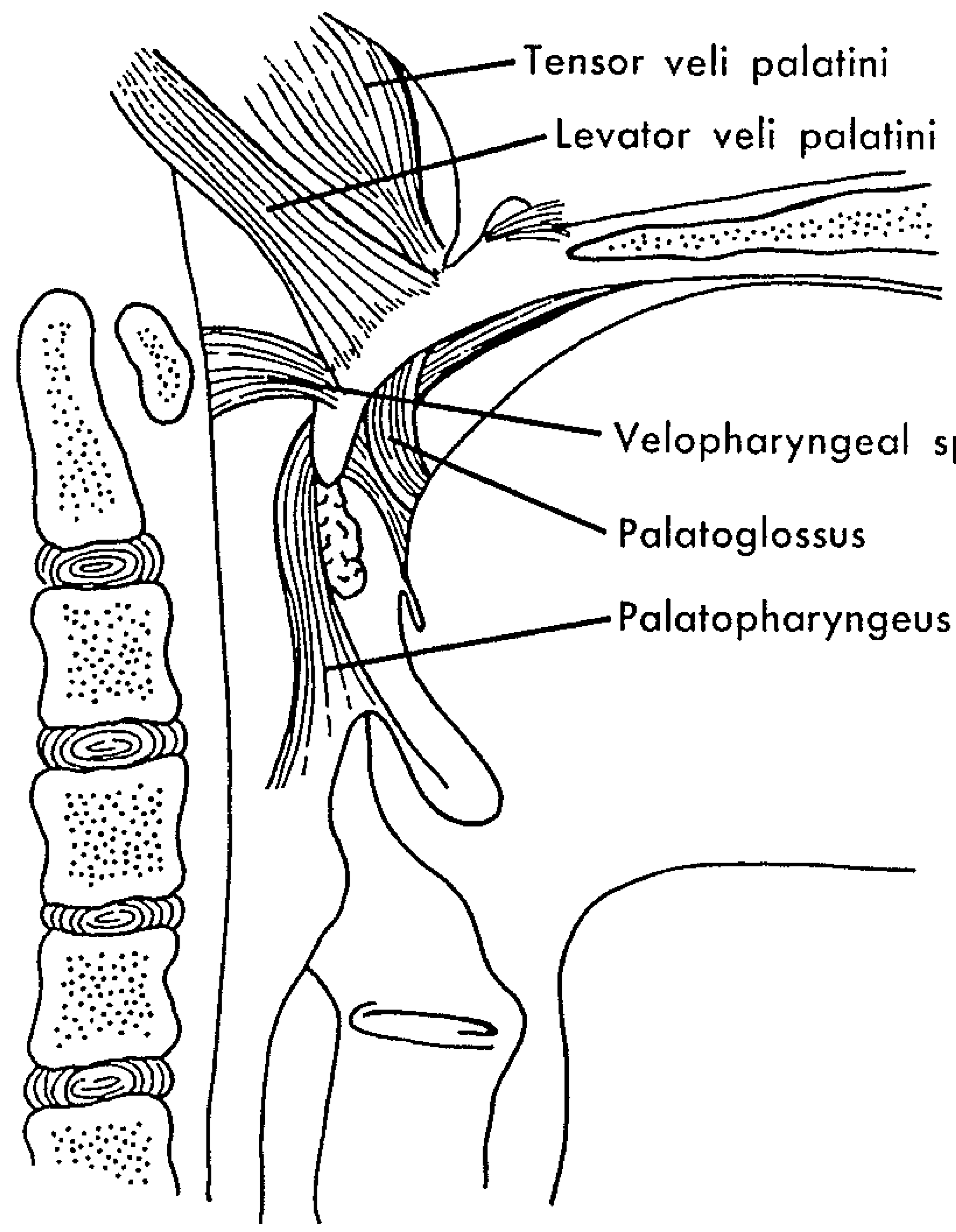


Fig. 23 Soft palate muscles. (Barrett and Hanson, 1978)

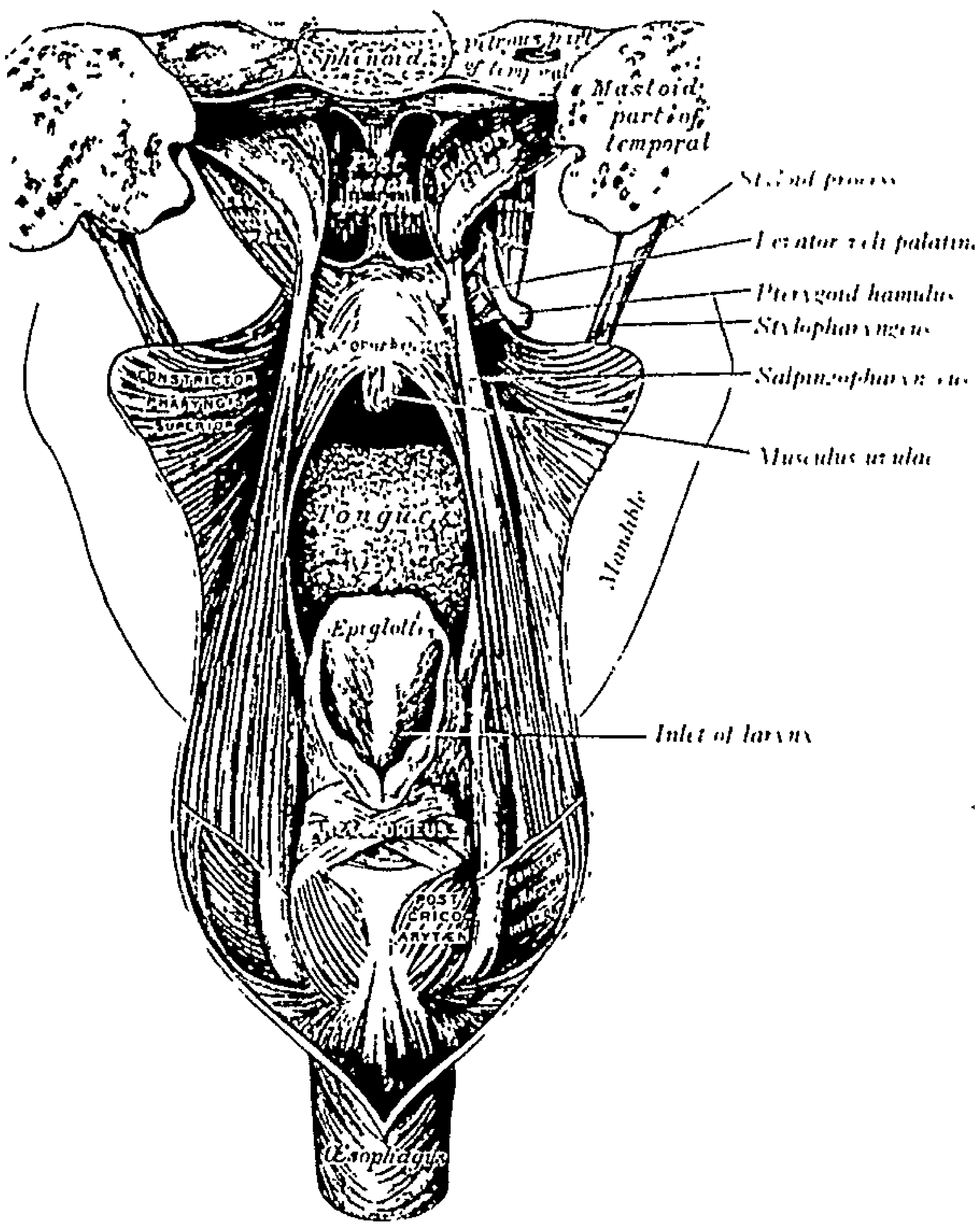


Fig. 24 Soft palate muscles: posterior view. (Williams and Warwick, 1980)

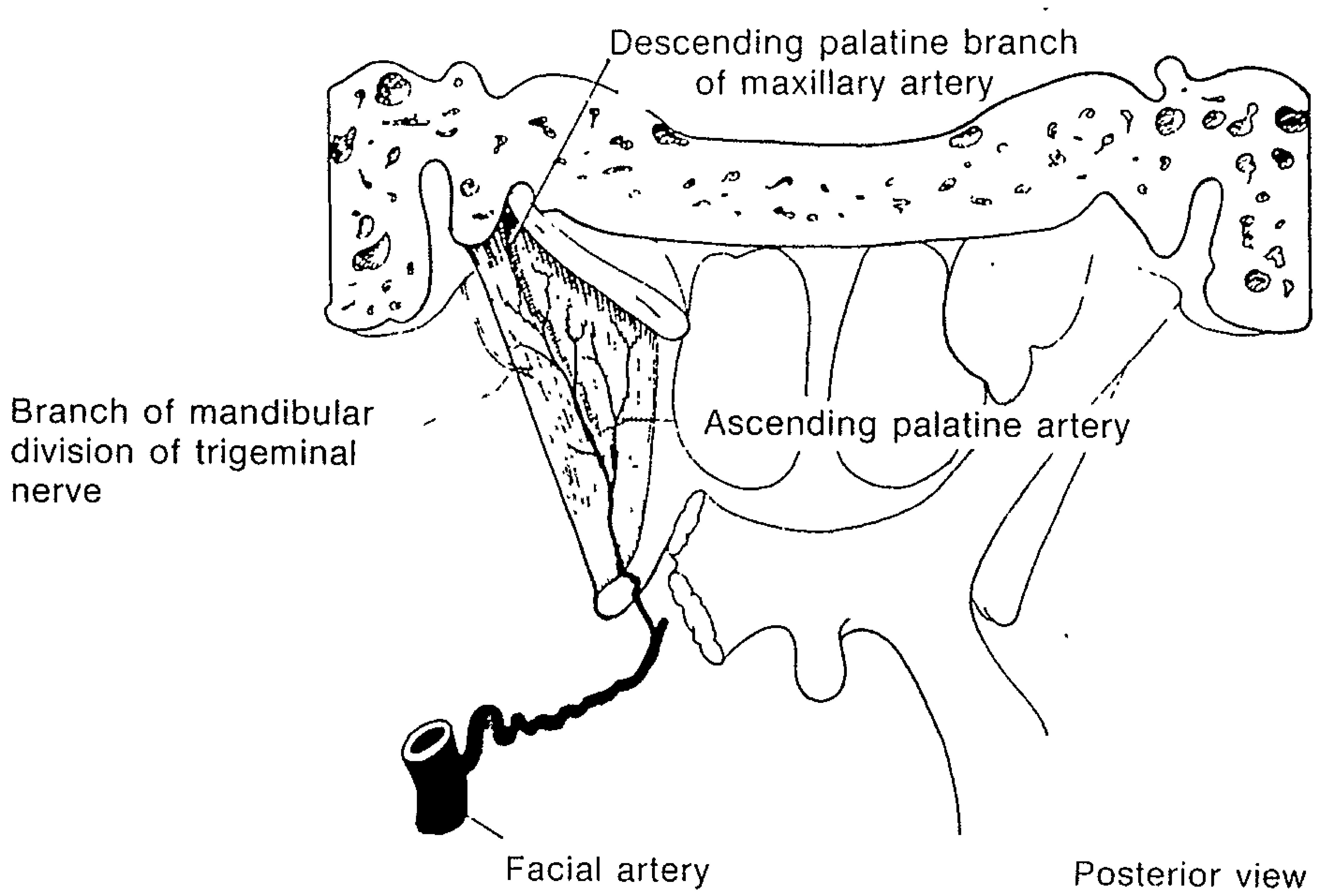


Fig. 25 Tensor veli palatini. (Fried, 1976)

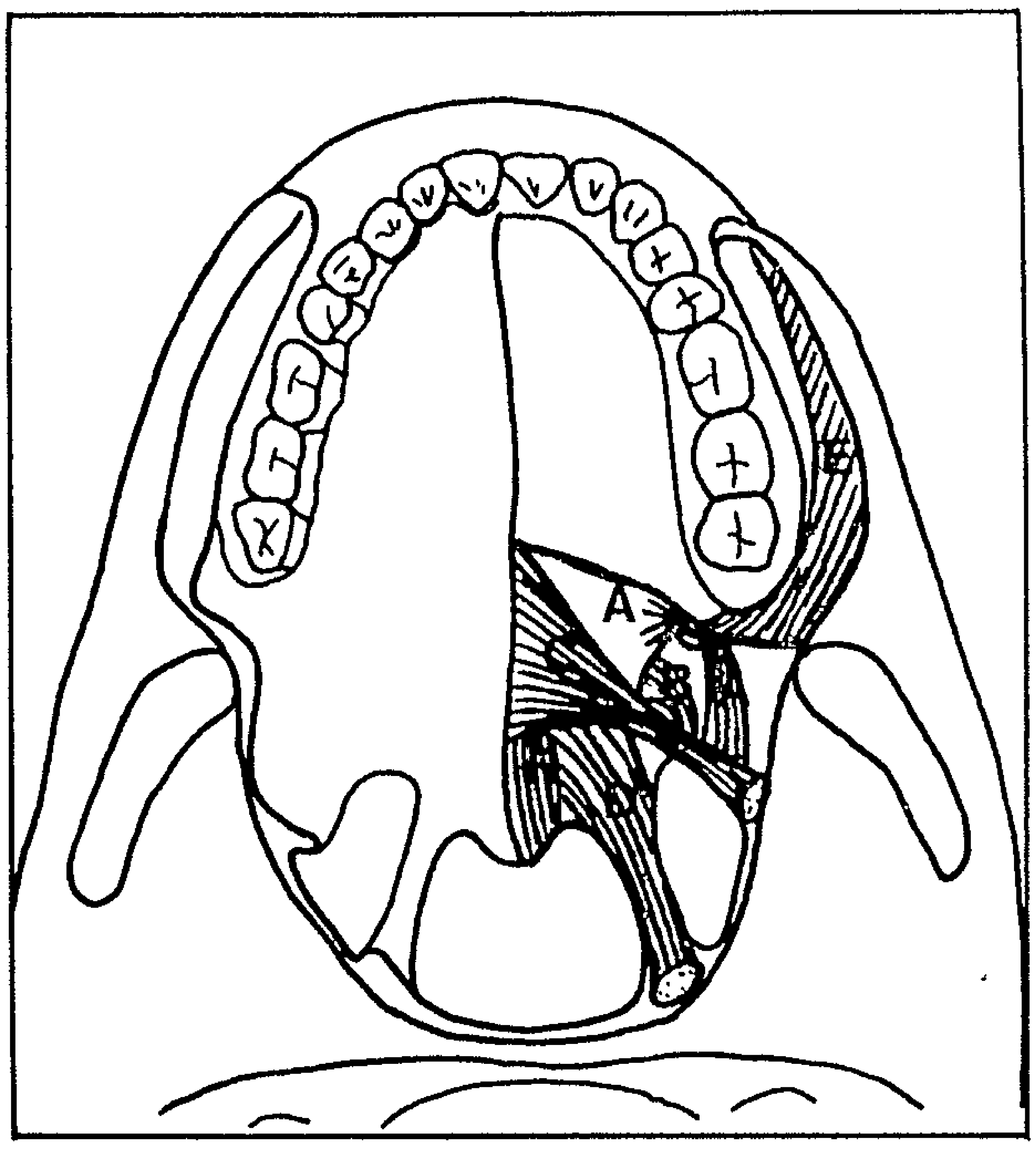


Fig. 26 Soft palate muscles: inferior view. A, tensor palati muscles. B, levator palati muscles. C, palatoglossus muscles. D, palatopharyngeus muscles. E, buccinator muscle. F. musculus uvulae. (Berkovitz et al., 1978)

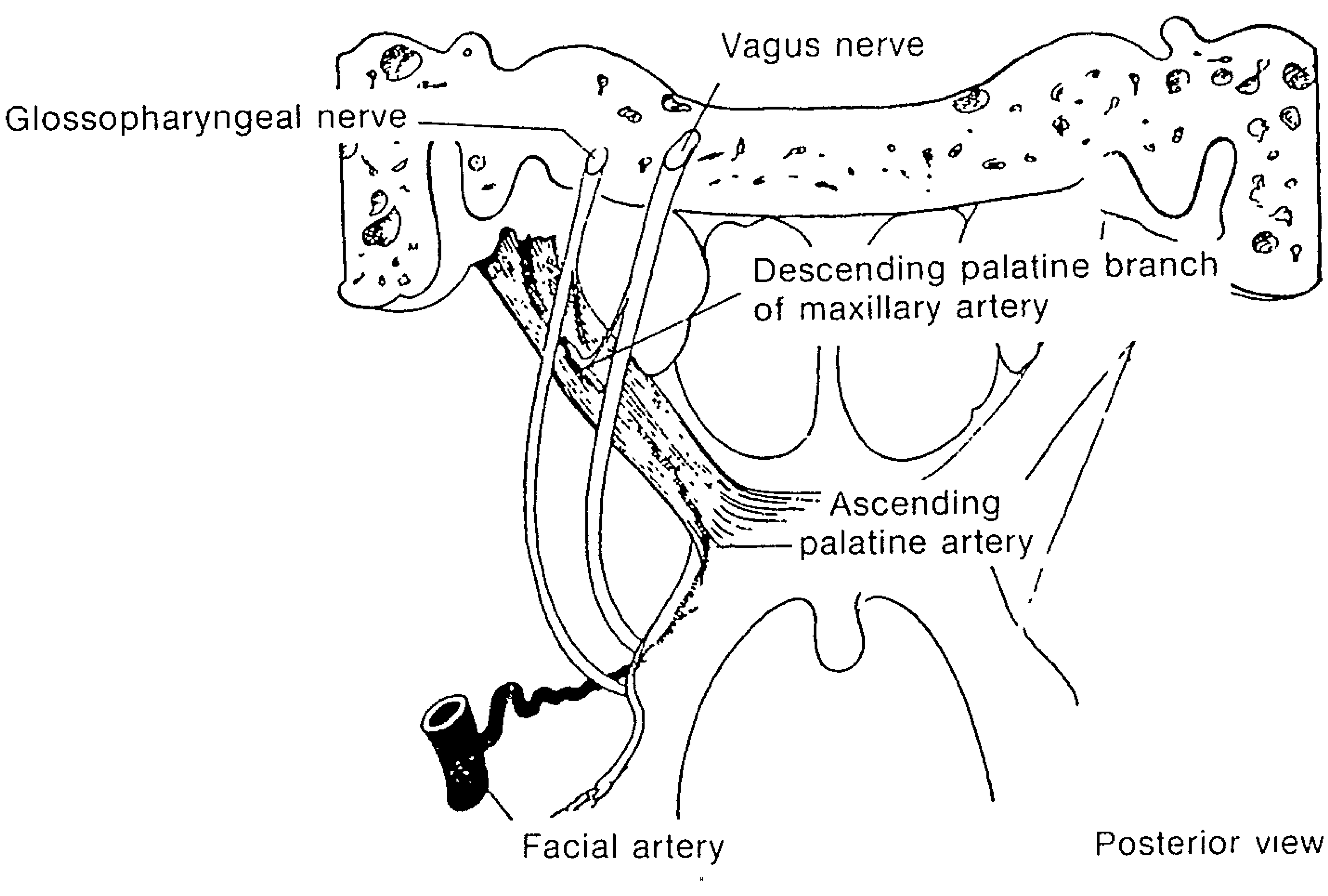


Fig. 27 Levator veli palatini. (Fried, 1976)

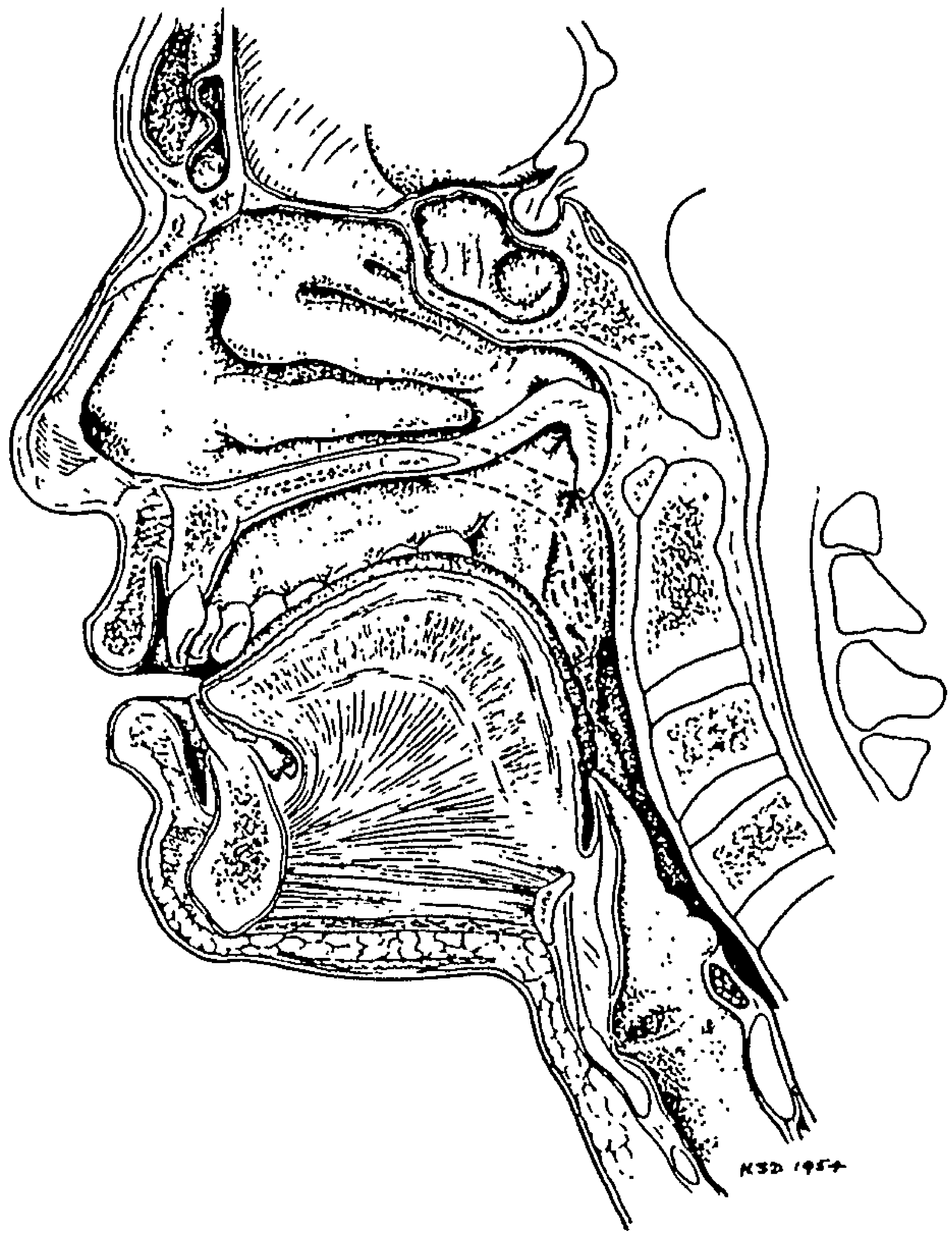


Fig. 28 During speech the soft palate rises, and contact is made with the pharyngeal wall above the level of the arch of the atlas. During swallowing (dotted line) the pharynx is occluded at a lower level. (Holdsworth, 1970)

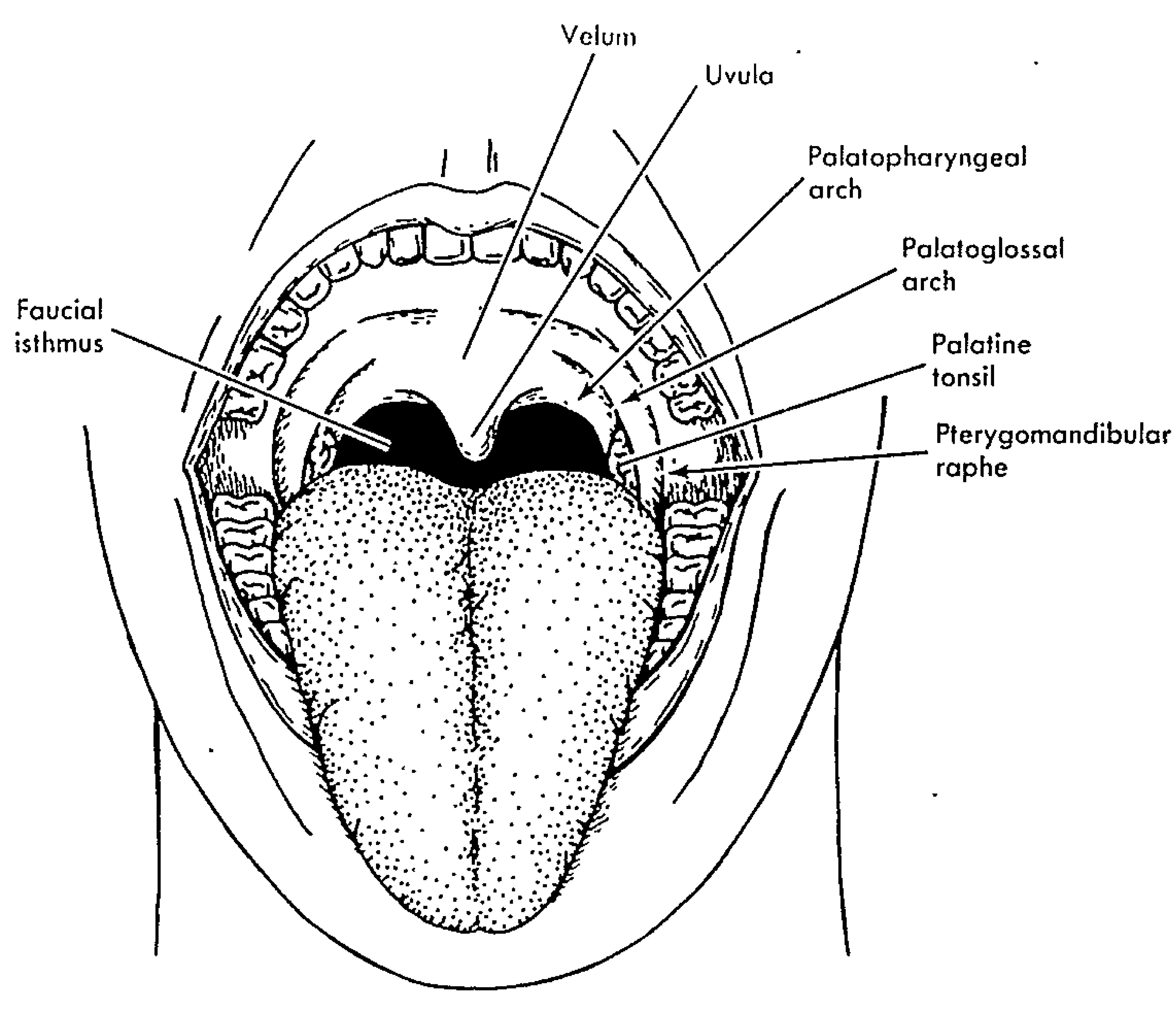


Fig. 29 Oral cavity: posterior region. (Barrett and Hanson, 1978)

The nerve supply is via the pharyngeal plexus.

Velopharyngeal Sphincter (Fig.23): This muscle, described by Holdsworth (1970) and Berkovitz et al. (1978) as being part of the pharyngeal superior constrictor, has fibres that pass horizontally around the sides of the pharynx, from the velum to the midline of the posterior pharyngeal wall (Whillis, 1930). As described by Barrett and Hanson (1978) it has dual, but simultaneous, functions. It draws the soft palate posteriorly and is thought to pull forward a horizontal fold of the posterior pharyngeal wall known as 'Passavant's pad' or 'ridge' (Carpenter and Morris, 1968). This action mainly occurs during one phase of swallowing. However, in the field of Speech Pathology, Passavant's pad is sometimes regarded as a compensatory response to velopharyngeal incompetence, usually in patients with cleft palates (McWilliams, Morris, and Shelton, 1984; Godfrey, 1985; McWilliams, 1985). Basically there are two distinct velar-ridge relationships (Holdsworth, 1970): (a) during speech the soft palate contacts above the ridge and (b) during swallowing the soft palate contacts on or below the ridge (Fig.28). Overall, though, there is a great deal more to be learned about the function of this structure.

The nerve supply is via the pharyngeal plexus.

Williams and Warwick (1980) and Barrett and Hanson (1978) include the Palatopharyngeus, which is usually regarded as a pharyngeal muscle, and the Palatoglossus, which can be included in any or all of three groups - lingual, soft palate and pharyngeal musculature.

It is only significant here to note that the palatoglossus has a dual function depending on which end of the muscle is more firmly fixed at the time. As mentioned previously both ends of this muscle attach to mobile structures. Contraction of this muscle may either draw the sides of the tongue up and back, or draw down the sides of the velum.

It is also significant to note at this stage that the soft palate (velum) is a mobile structure and, like the tongue, is composed largely of muscles. Barrett and Hanson (1978) point out that because these muscles enter the palate from various outside locations - some above, some below, and some behind the velum - it is given the ability to move in many directions as it combines or separates the oral and nasal cavities, the nasal cavity and the pharynx, etc. (Fig. 29).

Of further significance, as will be discussed later, is that in this region voluntary contraction of muscles begins to give way to reflex contraction. Barrett and Hanson (1978) again point out that posterior to the velum, direct voluntary control over muscle is lost, contraction occurs only as a secondary reaction to some volitional action in the mouth. According to these authors:

> "... we cannot deliberately set in motion the chain of constrictor muscles lining the pharyngeal wall; we can only perform a voluntary act that will trigger their reflexive contraction." (p.78)

They add:

> "The importance of the foregoing lies in the fact that, among the patients we see, many display inactivity, or inappropriate activity, of the palatal muscles. While voluntary control of these muscles may not be exercised it is accessible, and needs to be established in most cases." (p.78)

2.3.4 Pharyngeal Musculature (Figs. 9, 30-34)

Again there is division of opinion among the authors as to the description of the pharyngeal muscles. Some authors (Fried, 1976; Riviere, 1983; Williams and Warwick, 1980) include the soft palate muscles, and one (Fried, 1976) includes a glossal muscle, the palatoglossus, while Barrett and Hanson (1978) include the "velopharyngeal muscles", which are described as entering this region. This description includes all of these muscles together.

The pharynx is described by Riviere (1983) as being a muscular tube that begins at the base of the skull and ends in the oesophagus and larynx. It consists of three overlapping constrictor muscles and three smaller muscles, all of which function in swallowing by elevating or dilating the pharynx. The pharynx may be divided into three functional areas - the naso-, the oro-, and the laryngopharynx.

The nasopharynx is that area of the pharynx posterior to the nasal cavities above the plane of the soft palate. The oropharynx is that area below the nasopharynx and behind the oral cavity. It extends inferiorly to the level of the hyoid bone. The laryngopharynx is that part of the pharynx below the hyoid bone which contains the larynx.

Superior Constrictor: This muscle arises from the lower part of the medial pterygoid plate, the pterygomandibular raphe, and from the alveolar process of the mandible, behind the mylohyoid line. The fibres pass posteriorly and superiorly to insert on a fibrous band - the median raphe. This raphe runs from the pharyngeal tubercle of the occipital bone to the inferior border of the inferior constrictor of the pharynx.

Middle Constrictor: The origin of the middle constrictor, a fan-shaped muscle, is the whole length of the upper border of the greater cornu of the

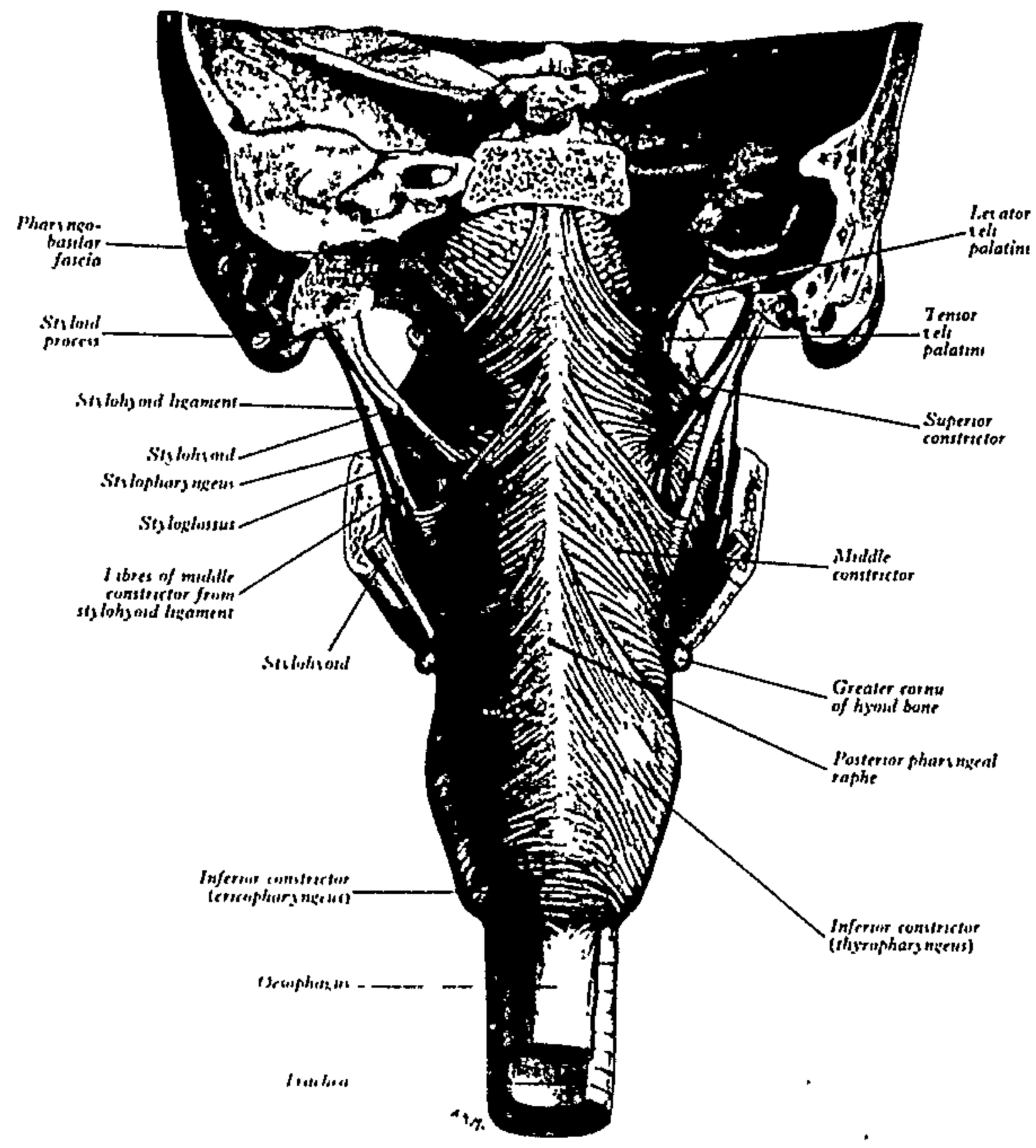


Fig. 30 Pharyngeal muscles: posterior view (A). (Williams and Warwick, 1980)

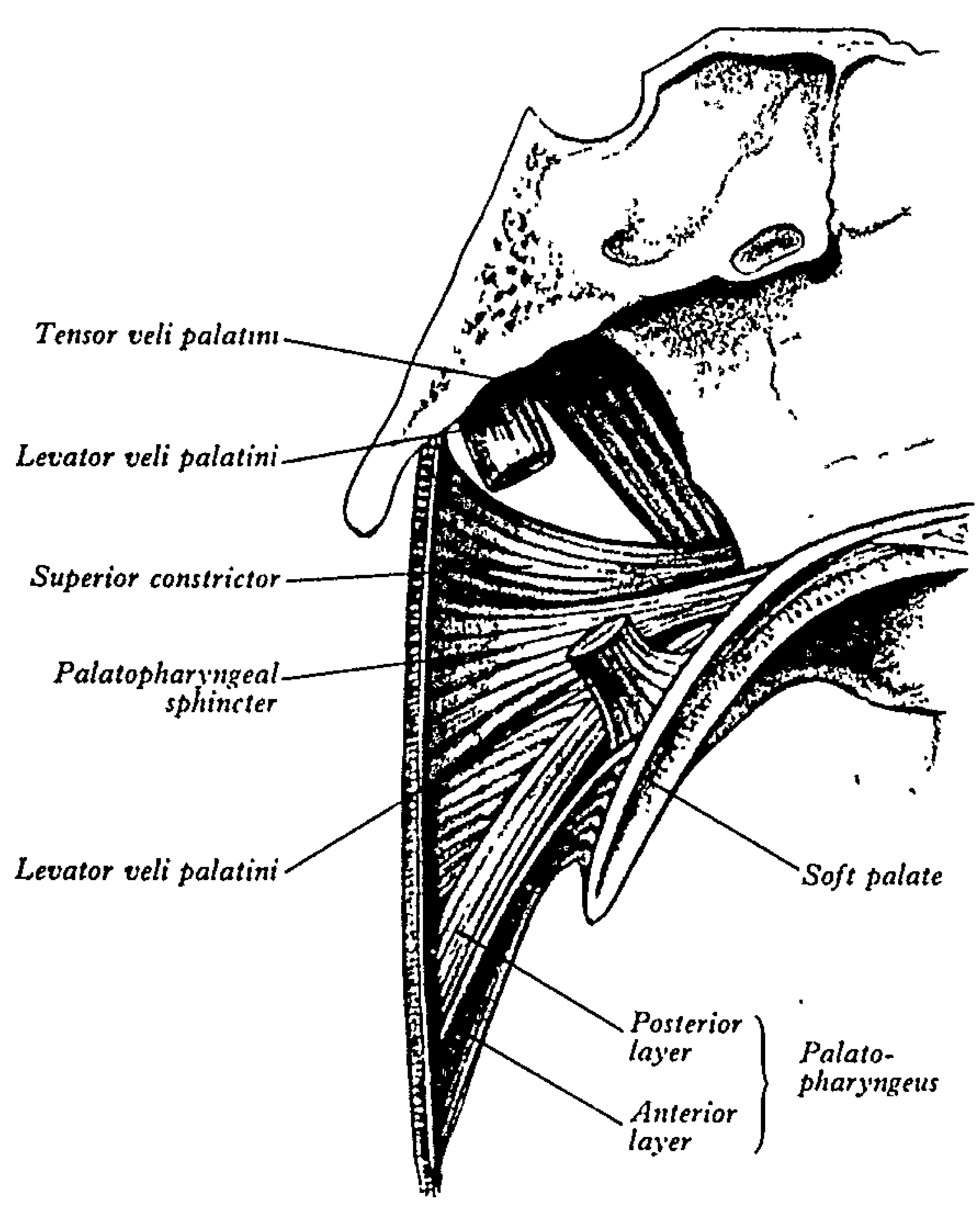


Fig. 31 Soft palate muscles and adjoining pharyngeal wall. (Williams and Warwick, 1980)

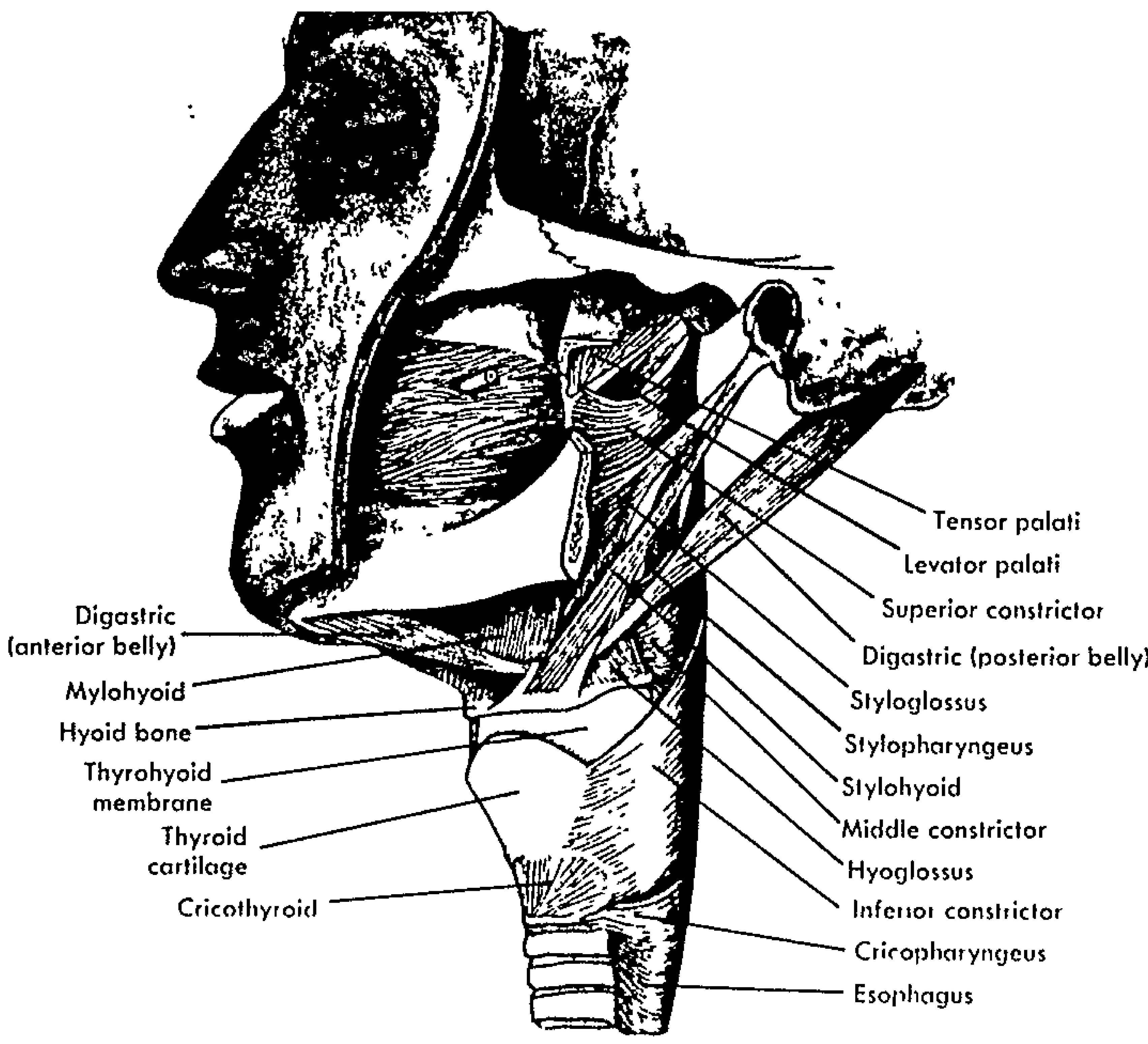


Fig. 32 Pharyngeal muscles: lateral view. (DuBrul, 1980)

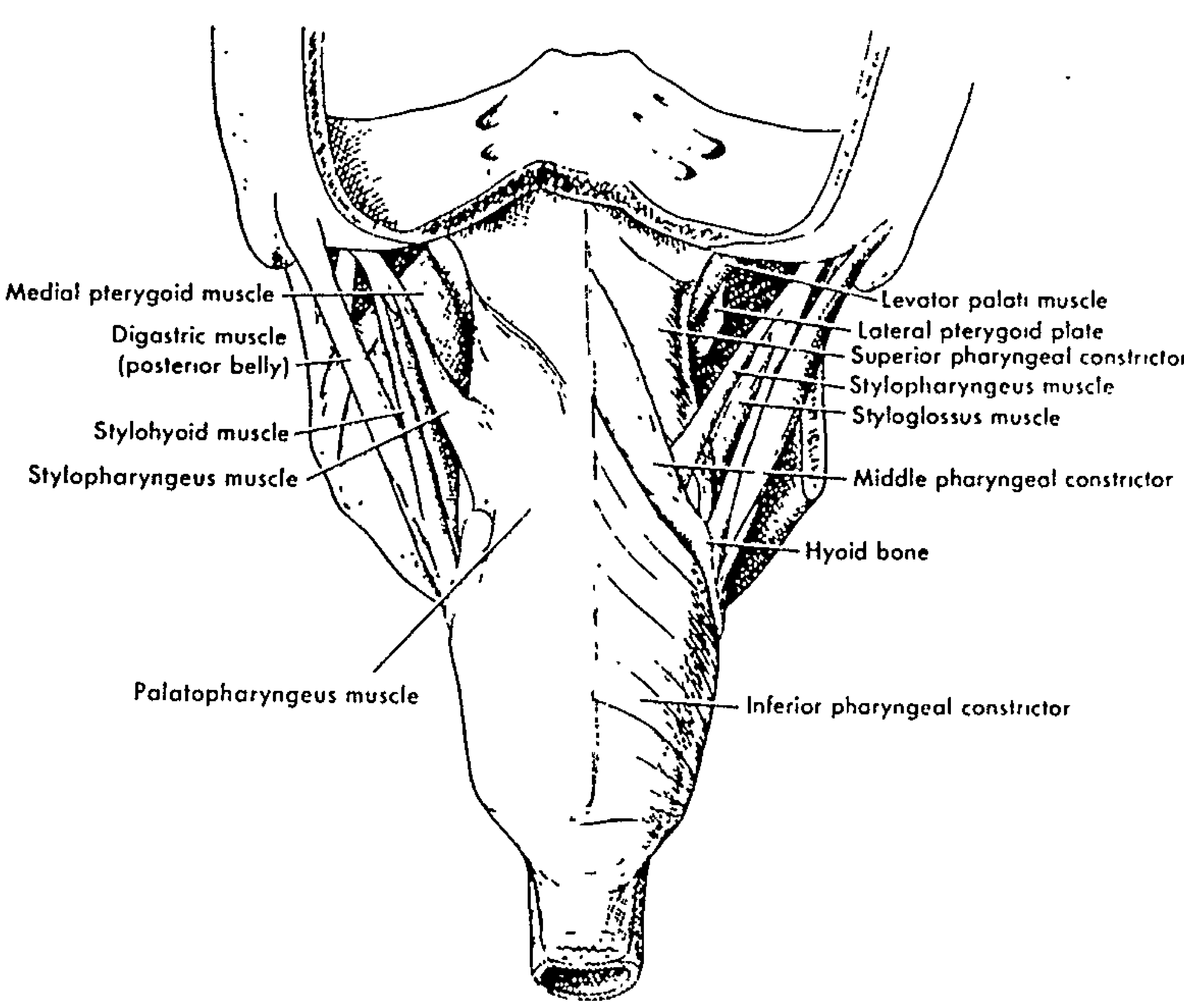


Fig. 33 Pharyngeal muscles: posterior view (B). (DuBrul, 1980)

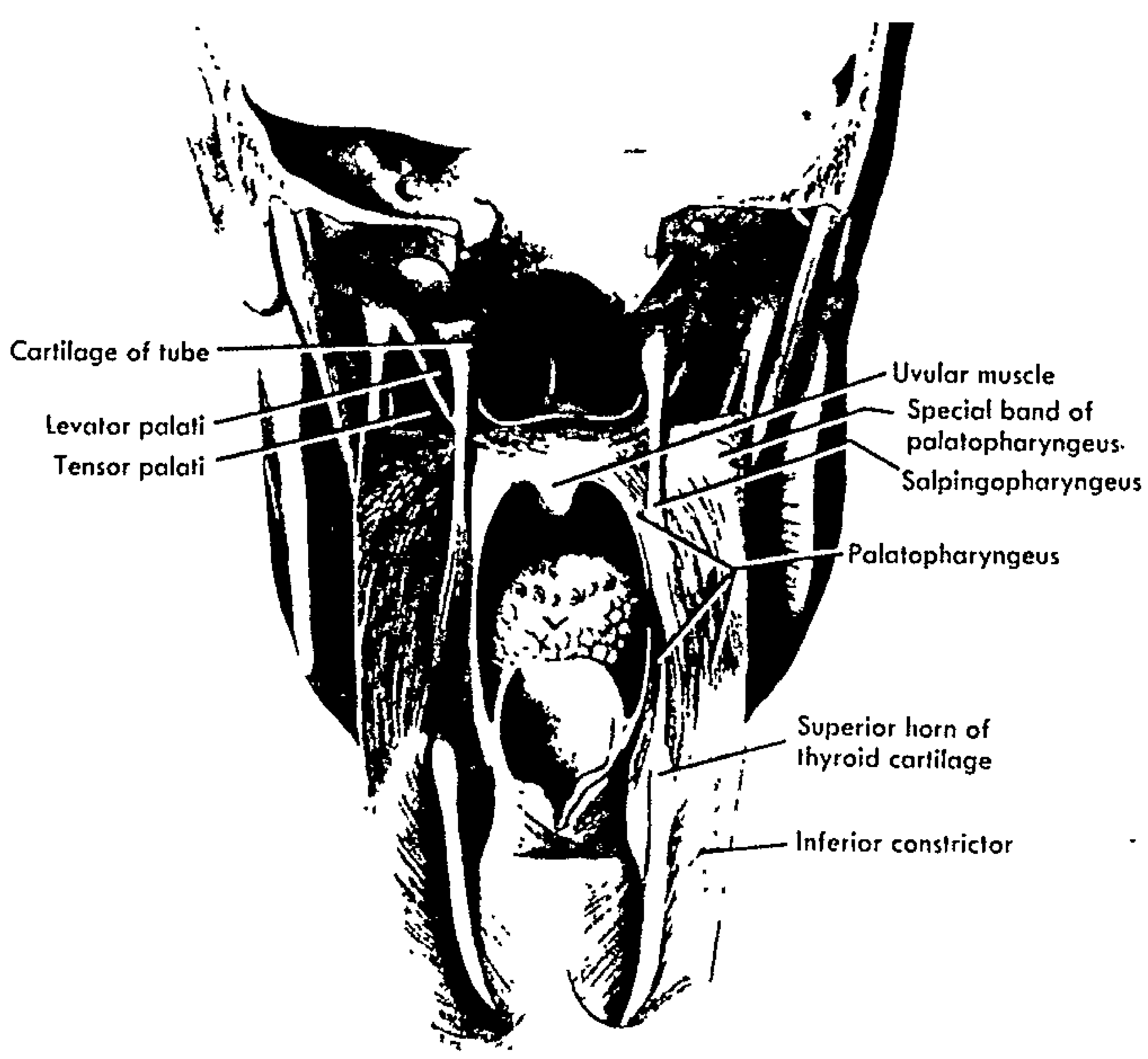


Fig. 34 Pharynx: longitudinal muscles. (DuBrul, 1980)

hyoid bone, from the lesser cornu and from the stylohyoid ligament. The fibres pass posteriorly and superiorly as well as posteriorly and inferiorly. The upper fibres overlap the lower fibres of the superior constrictor, whereas the lower fibres descend beneath the upper fibres of the inferior constrictor. The middle constrictor inserts posteriorly on the median raphe.

Inferior Constrictor: This muscle is the widest and thickest of the three constrictors. It originates from the larynx (cricoid and thyroid cartilages). The fibres fan out to insert on the fibrous median raphe. The most superior fibres of this muscle insert at a point as high as the midportion of the superior constrictor.

Palatoglossus: Described previously, it forms the anterior tonsillar pillar. It arises from the anterior surface of the soft palate and inserts into the dorsum and side of the tongue.

Palatopharyngeus: A long fleshy muscle, it originates in the soft palate. It passes laterally and inferiorly and forms the posterior tonsillar pillar. It inserts into the posterior border of the thyroid cartilage of the larynx and the pharyngeal aponeurosis.

Salpingopharyngeus: A thin, vertically oriented muscle, it originates near the opening of the auditory tube in the posterior nasal cavity, just above the soft palate. It passes downward and blends with the Palatopharyngeus.

Stylopharyngeus: This long, slender, cylindrical muscle arises from the styloid process. It passes inferiorly, between the middle and superior constrictor, and spreads out and intermingles with its neighbouring muscle fibres in the pharynx.

As Fried (1976) describes, the actions of these muscles are interesting. As swallowing begins, the pharynx is elevated and dilated. As soon as the bolus of food reaches the pharynx, the elevators and dilators relax and the pharynx descends. Then the constrictors contract harmoniously to propel the bolus into the oesophagus and the stomach.

The nerve supply to the pharyngeal muscles is via the pharyngeal plexus, with the exception of the stylopharyngeus which is supplied by the Glossopharyngeal nerve.

2.3.5 Neck Musculature (Figs. 35, 36)

The anterior muscles of the neck are divided into two groups - those muscles above the hyoid bone, the Suprahyoids, and those below it - the Infrahyoids. Both groups are attached to the hyoid bone and act to support each other, using the hyoid bone as a movable fulcrum, during the process of mastication and swallowing.

2.3.5.1 Suprahyoid Muscles (Fig. 37)

These muscles function either to elevate the hyoid bone or to depress the mandible. If the mandible is fixed by contraction of the muscles of mastication, the contraction of the suprahyoids will elevate the hyoid bone and the larynx. However, if the hyoid bone is fixed by the contraction of the infrahyoids, contraction of the suprahyoids will open and/or depress the mandible (Fried, 1976).

Digastric (Fig. 37): This muscle is made up of two bellies attached to one another, end to end. The anterior belly originates on the medial and inferior border of the mandible close to the symphysis and loops inferiorly and posteriorly. The posterior belly arises from the mastoid notch of the temporal bone and swings inferiorly and anteriorly. The two bellies meet at a round intermediate tendon which in turn gives rise to the suprahyoid aponeurosis, which is attached to the hyoid bone.

The nerve supply to the posterior belly is via a branch of the Facial nerve. The anterior belly is innervated by the mandibular branch of the Trigeminal nerve.

Mylohyoid (Figs. 38,39): This is a triangular-shaped muscle arising from the whole length of the mylohyoid line on the medial aspect of the mandible. The posterior fibres pass medially and inferiorly to insert into the anterior

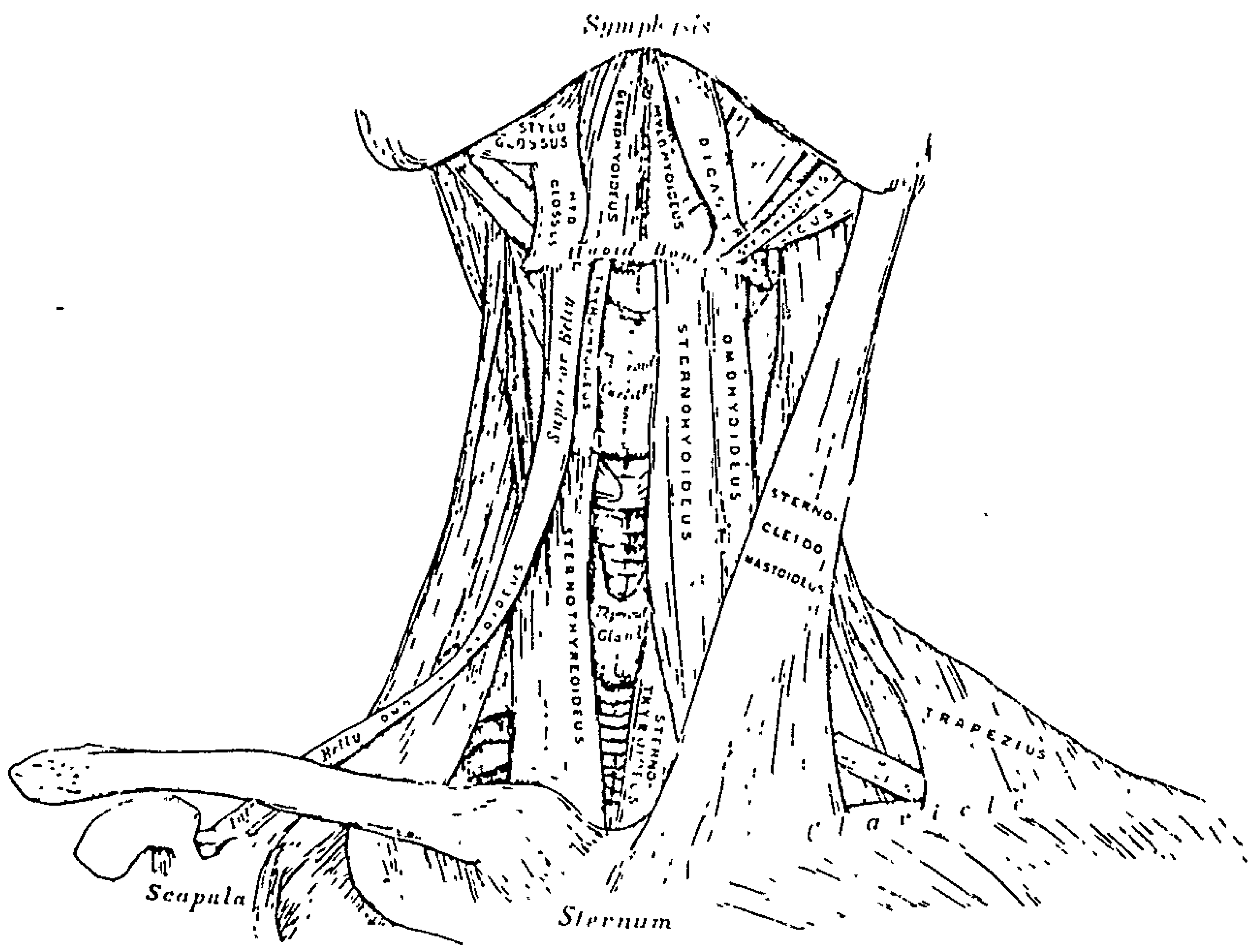


Fig. 35 Neck muscles: anterior view. (Fried, 1976)

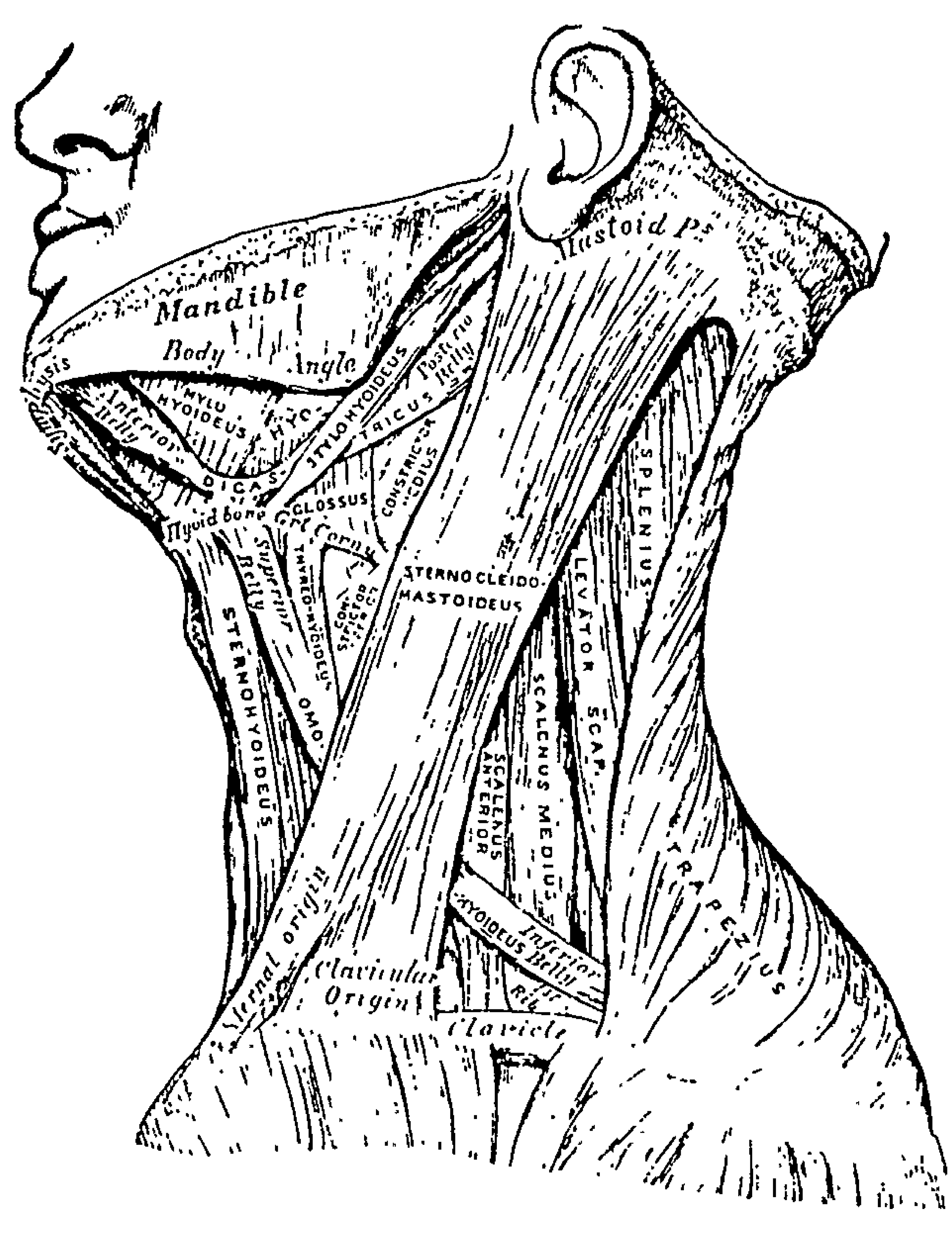


Fig. 36 Neck muscles: lateral view. (Fried, 1976)

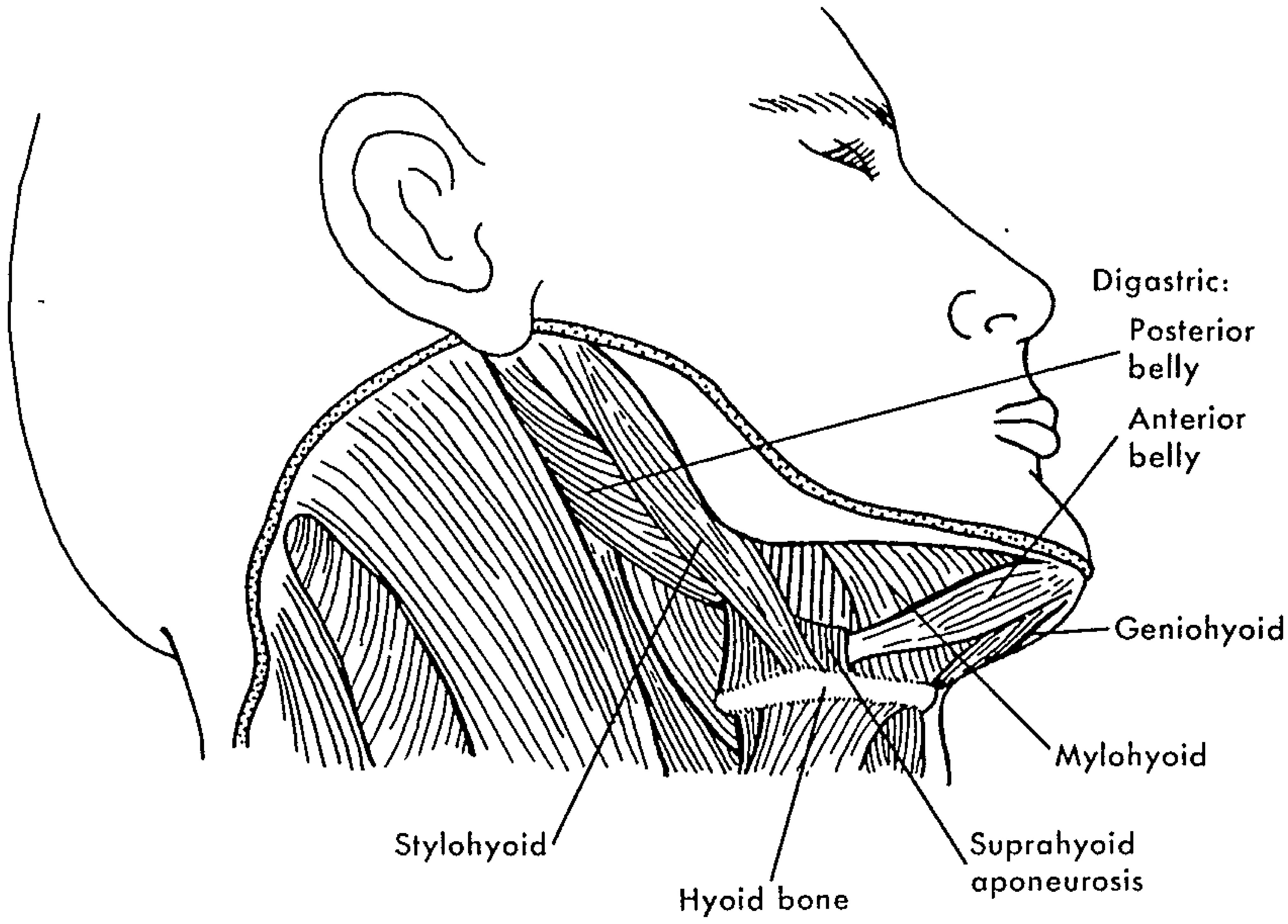


Fig. 37 Suprahyoid muscles. (Barrett and Hanson, 1978)

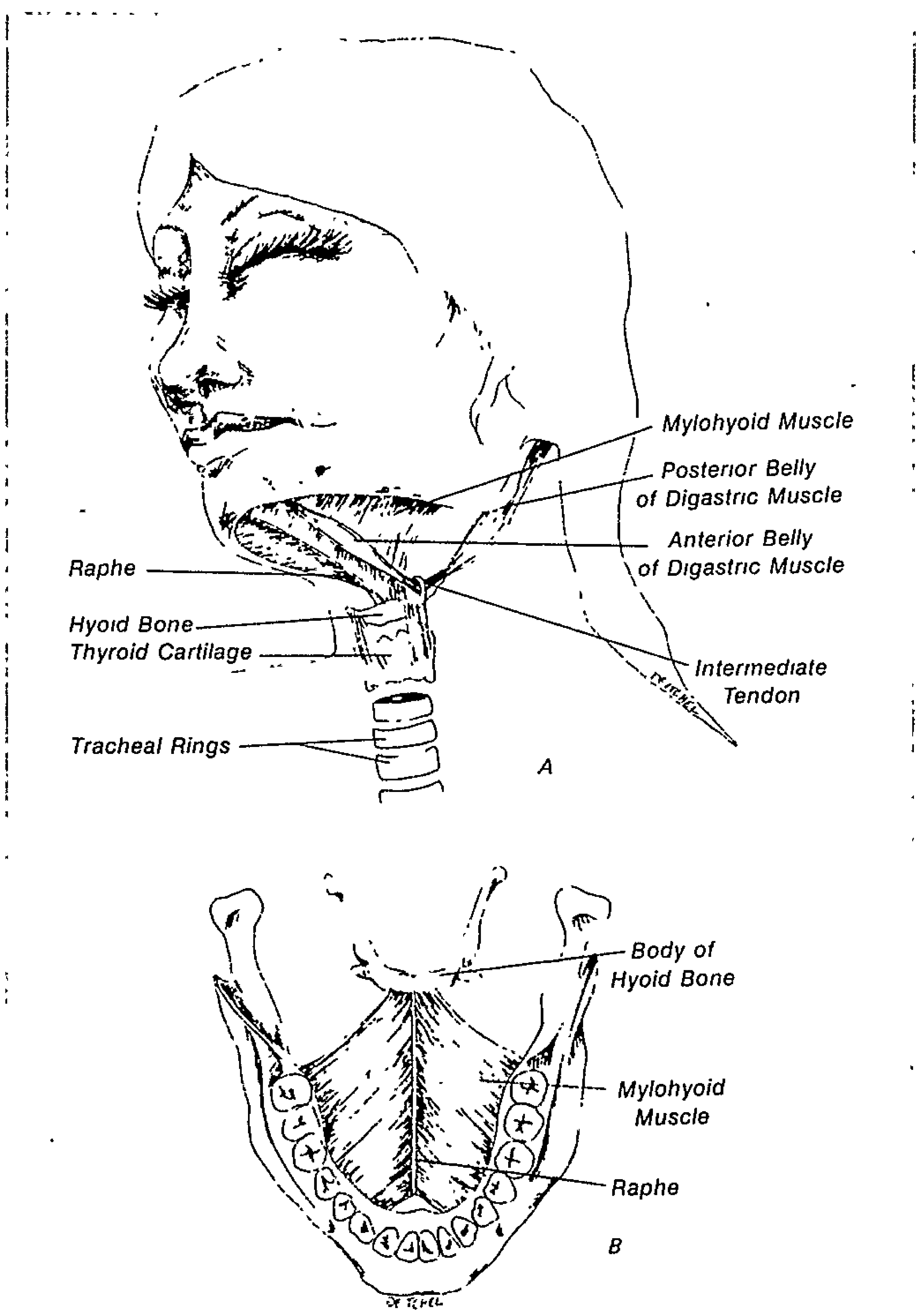


Fig. 38 Mylohyoid muscle. A, external surface. B, internal surface. (Fried, 1976)

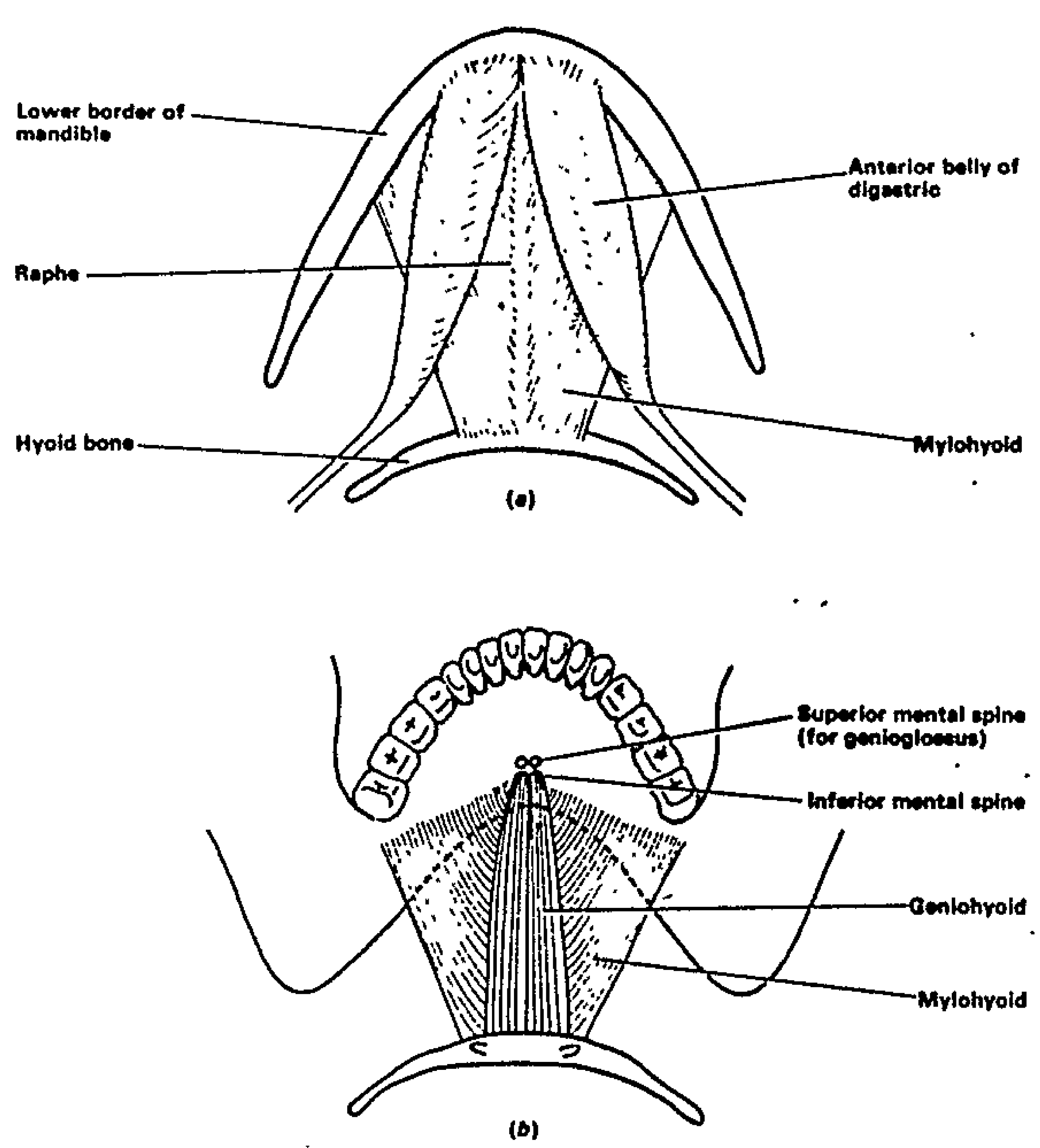


Fig. 39 Floor of the mouth.
(a) Seen from below - the anterior bellies of the digastric muscles overlie the mylohyoids which unite in a midline raphe.
(b) Seen from above and behind - the two geniohyoids overlie the mylohyoids.
(McMinn and Hobdell, 1974)

part of the body of the hyoid bone. The anterior fibres join a median raphe which runs from the symphysis menti to the body of the hyoid bone. The raphe unites the two muscles in the midline, so forming a complete muscular sheet between the sides of the mandible. The superficial surface is covered by the platysma muscle and the anterior belly of the digastric. The superior surface lies under the geniohyoid muscle in the midline. Two of the extrinsic muscles of the tongue - the hyoglossus and the styloglossus - also lie close to this surface.

The nerve supply is via the Trigeminal nerve.

Geniohyoid (Fig. 39): This is a narrow muscle which arises from the inferior mental spine on the medial aspect of the midline of the mandible and is inserted into the anterior surface of the body of the hyoid bone. As described previously it lies on the superior surface of the mylohyoid.

It is innervated by the first and second cervical nerves via the cervical plexus.

Acting together, the mylohyoid and the geniohyoid muscles elevate the floor of the mouth during deglutition and also help to fix the hyoid bone, thus assisting the activity of the digastric and the middle constrictor muscles of the pharynx in elevating the larynx.

Stylohyoid: This muscle arises from the styloid process of the temporal bone. It is a thin, round muscle, which passes anteriorly and inferiorly to insert on the hyoid bone at the junction of the body and greater cornu.

It is innervated by the Facial nerve and acts to elevate and retract the hyoid bone or to fix the hyoid bone in cooperation with the infrahyoid muscles.

2.3.5.2 Infrahyoid Muscles (Fig. 35, 36)

The infrahyoid muscles act either to depress the hyoid bone and larynx or fix the hyoid bone so that it cannot be elevated by contraction of the suprahyoids. Although less critical to this discussion, their importance lies in the fact that they serve at the conclusion of the swallowing act to return the hyoid bone and the larynx to a neutral position.

Sternohyoid: This muscle originates on the sternum, near the lateral edge, where the sternum joins the clavicle. It passes superiorly and inserts on the body of the hyoid bone.

Omohyoid: This muscle originates on the scapula and passes anteriorly and superiorly to insert on the body of the hyoid bone, just lateral to the insertion of the sternohyoid. It contains a superior and an inferior belly joined together by an intermediate tendon.

Sternothyroid: This muscle arises medially to the sternohyoid, on the posterior surface of the most superior aspect of the sternum. It passes superiorly to insert on the thyroid cartilage and lies deep to the sternohyoid muscle.

Thyrohyoid: This muscle arises from the thyroid cartilage and inserts on the hyoid bone at the body and a part of the greater cornu.

The infrahyoids are innervated by first, second, and third cervical nerves via the cervical plexus.

2.3.6 Muscles of Mastication (Figs. 40-45)

The preceding group of muscles are sometimes regarded as accessory muscles of mastication (Fried, 1976; Riviere, 1983). A brief discussion of the four muscles of mastication follows.

Temporalis: This muscle is covered by a tough sheet of connective tissue, the temporal fascia. It originates from the entire temporal fossa and the temporal fascia. The anterior and superior fibres are vertical, while the posterior fibres are almost horizontal. The temporalis converges into an insertion on the medial aspect of the coronoid process of the mandible as well as the anterior and posterior borders of the process. Some fibres also insert on the anterior border of the ramus of the mandible to a point just behind the last molar tooth. The anterior and superior fibres elevate the mandible. The posterior fibres pull the mandible posteriorly.

Masseter: The masseter has a superficial and a deep origin. Superficial fibres arise from the inferior border of the anterior two-thirds of the zygomatic arch. The deeper fibres arise from the medial aspect of the posterior one-third of the zygomatic arch. The fibres converge and form a very powerful muscle that inserts on the angle and lower half of the lateral surface of the ramus and a portion of the upper half, including the lateral surface of the coronoid process. The masseter is a powerful elevator of the mandible.

Lateral Pterygoid: The lateral pterygoid originates from two heads. The upper head arises from the infratemporal surface of the sphenoid bone. The lower head arises from the lateral surface of the lateral pterygoid plate. The fibres converge and insert on the condylar head of the mandible, articular disc, and temporomandibular joint capsule. The muscle assists in opening the mouth by pulling the condylar head of the mandible forward. If the lateral

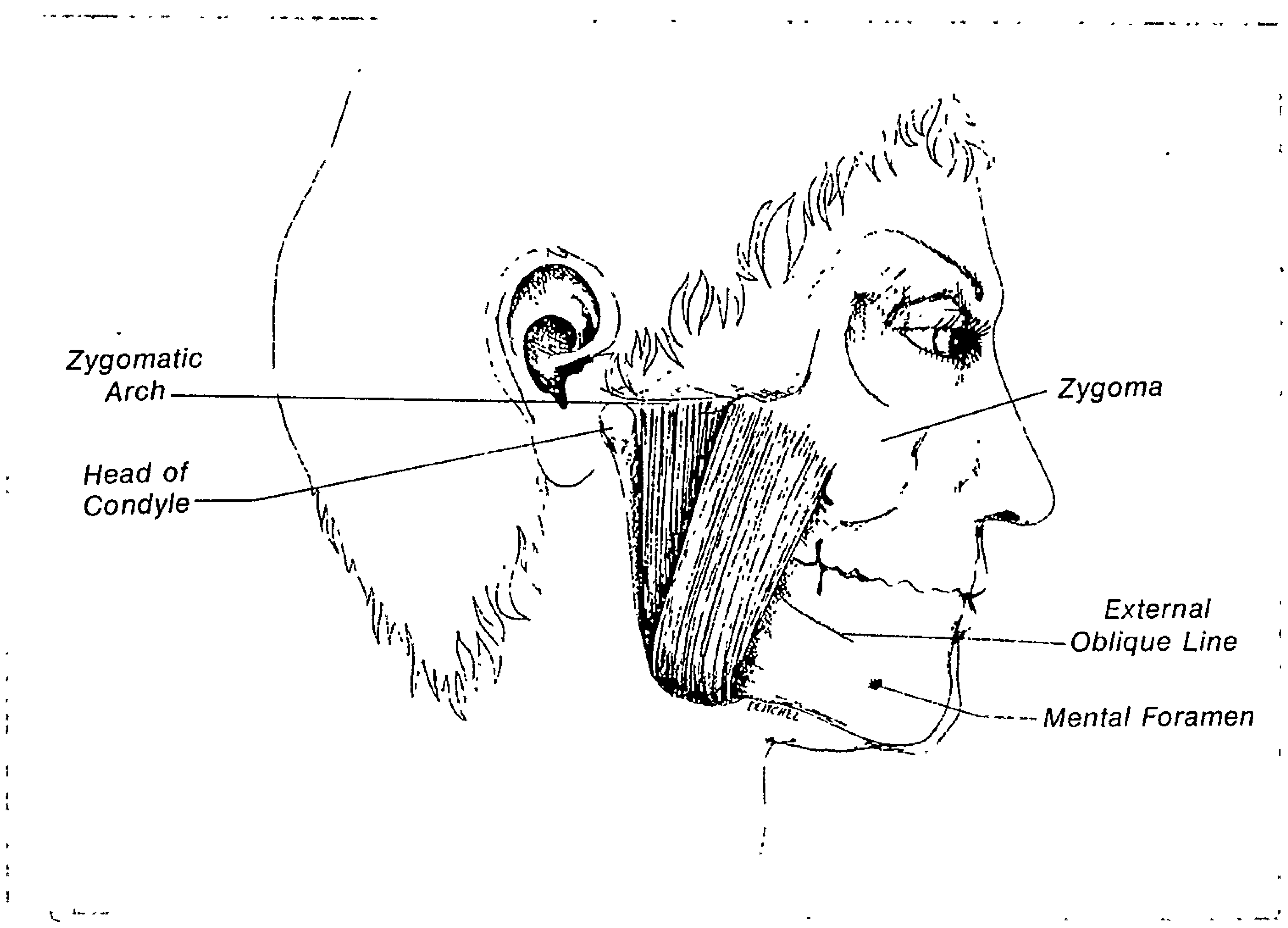


Fig. 40 Masseter muscle. (Fried, 1976)

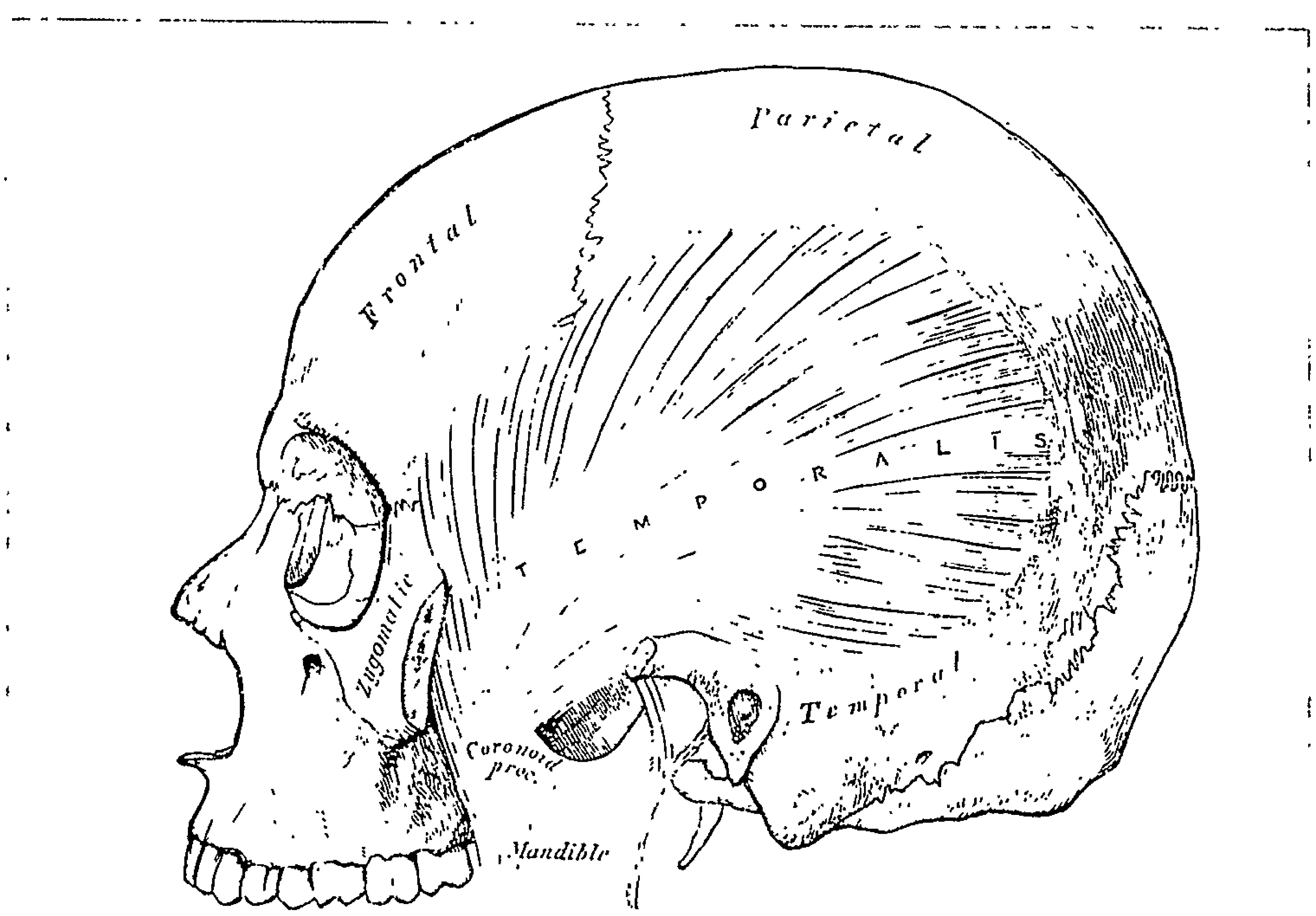


Fig. 41 Temporalis muscle. (Fried, 1976)

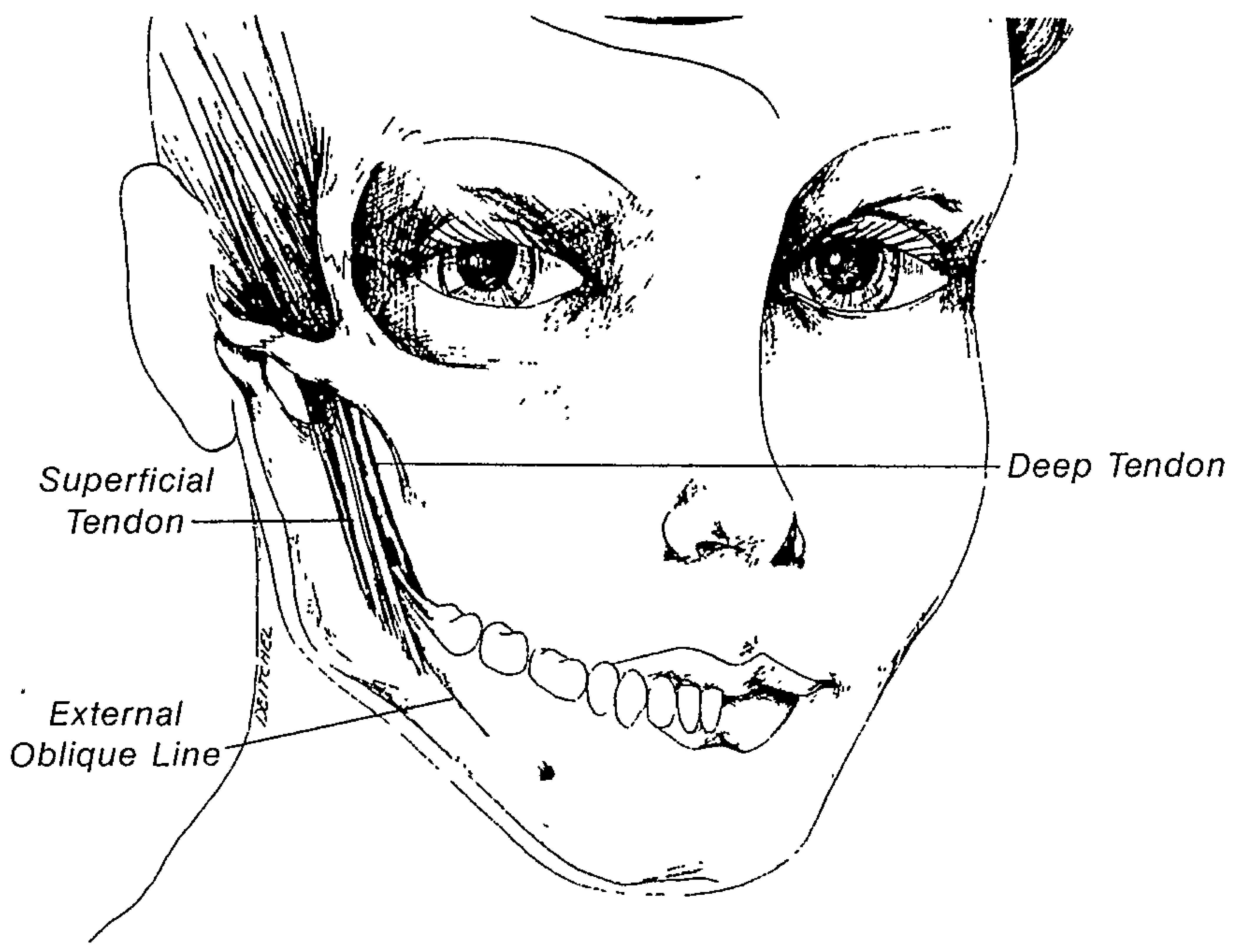


Fig. 42 Temporalis: superficial and deep tendon insertions. (Fried, 1976)

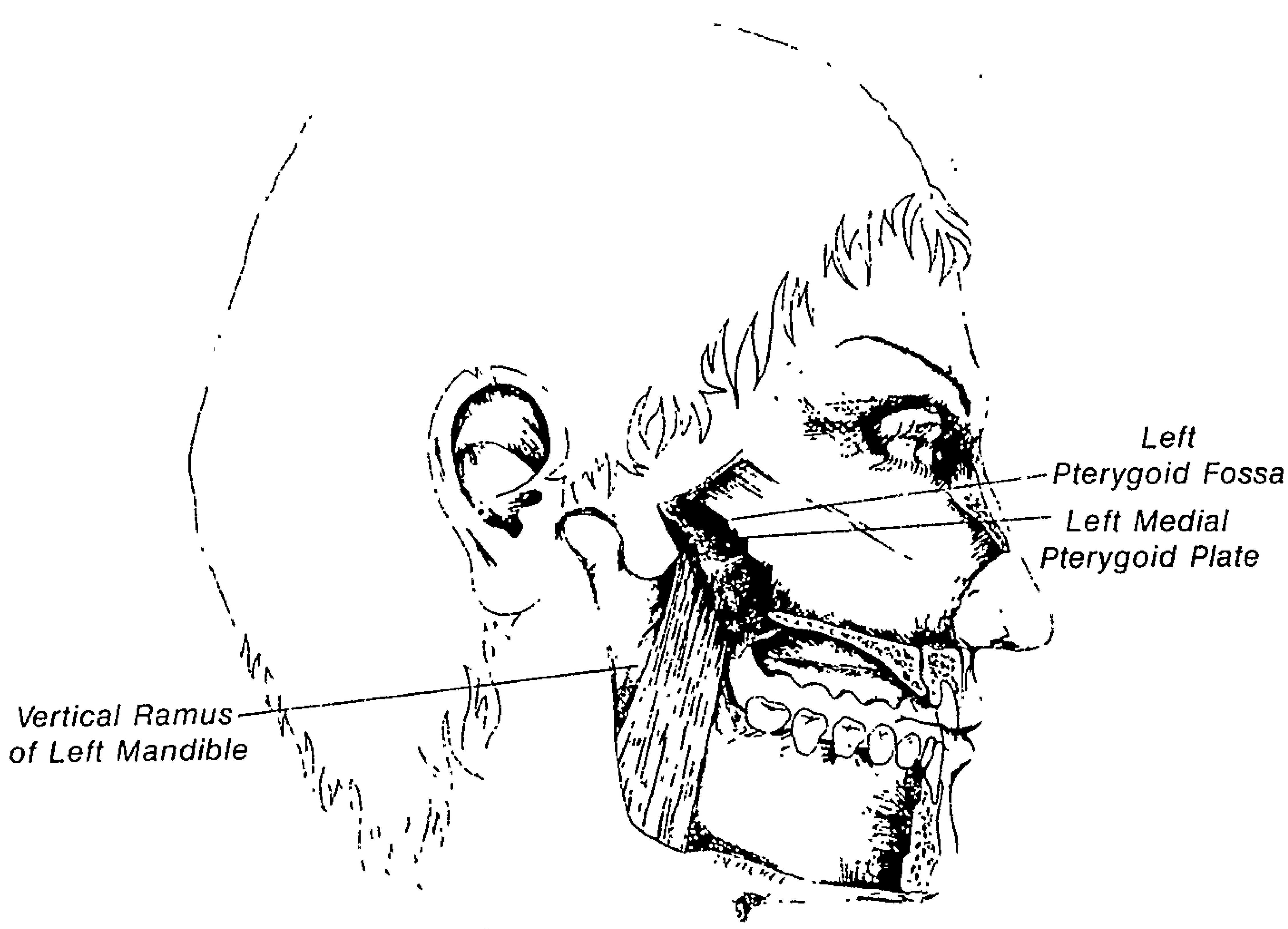


Fig. 43 Medial pterygoid muscle. (Fried, 1976)

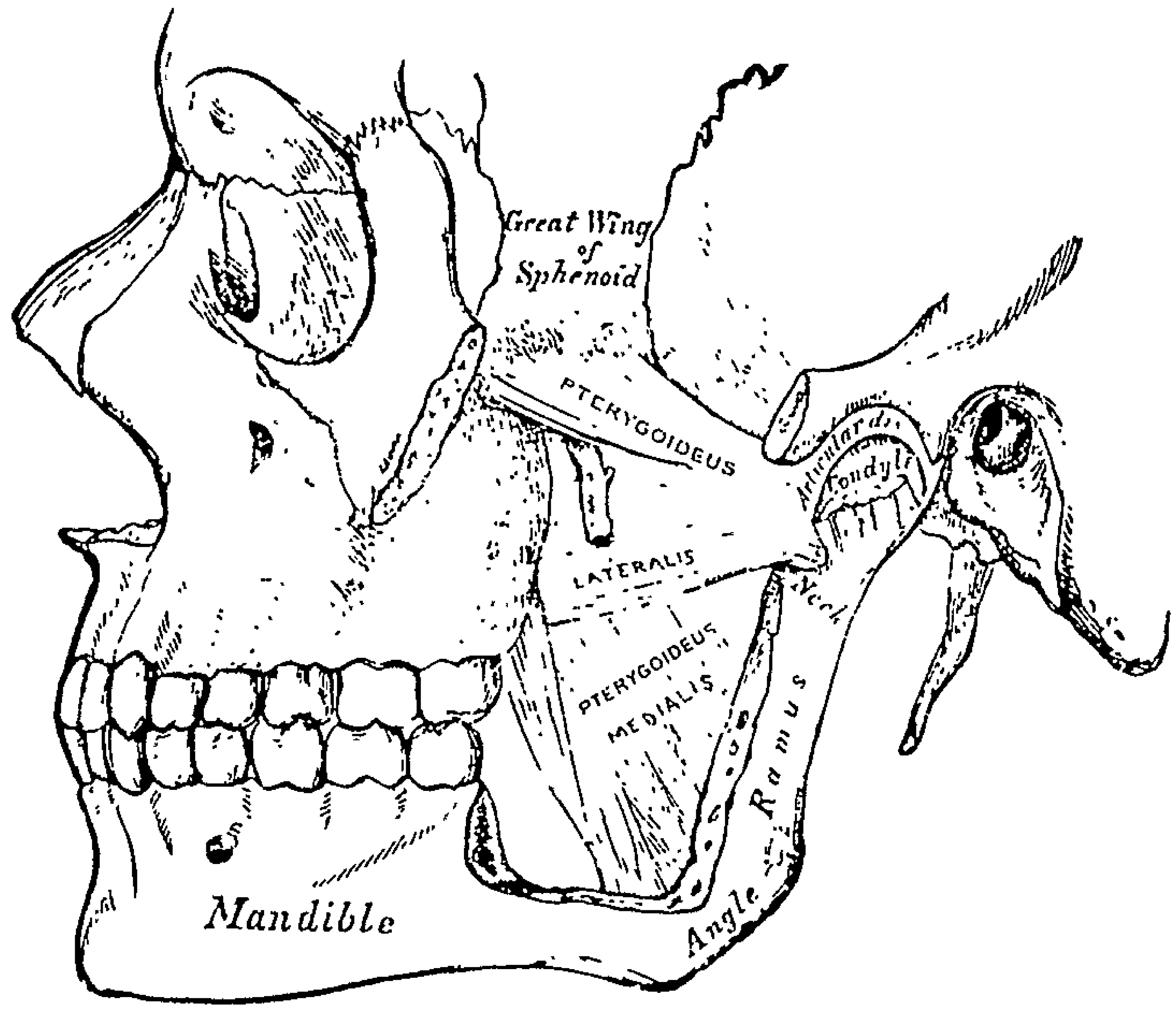


Fig. 44 Pterygoid muscles. (Fried, 1976)

Muscle	*Origin*	*Insertion*	*Function*
Masseter	Superficial: lower border of zygomatic arch Deep: medial surface of zygomatic arch	Superficial: outer surface of lower ramus and angle of mandible Deep: outer surface of upper ramus and coronoid process	Lifts mandible vertically
Temporalis	Temporal fossa of skull	Coronoid process and anterior margin of upper ramus	Elevates and retracts mandible
Internal pterygoid	Lateral pterygoid plate; palatine and maxillary bones	Lower margin of inner surface of ramus	Elevates and protrudes mandible
External pterygoid	Upper head: greater wing of sphenoid Lower head: outer surface of lateral pterygoid plate	Neck of condyle and articular disc of TMJ	Draws mandible forward; depresses mandible; moves mandible to side

*All innervated by the mandibular branch of cranial nerve V

Fig. 45 Table: Muscles of mastication. (Barrett and Hanson, 1978) pterygoid of one side contracts, it rotates the mandible on a vertical axis through the mandibular condyle of the opposite side.

Medial Pterygoid: The medial pterygoid has both superficial and deep origins. Superficial fibres from the maxillary tuberosity meet deep fibres from the medial surface of the lateral pterygoid plate. The muscle inserts on the angle of the medial surface of the ramus of the mandible below the mandibular foramen and posterior to the mylohyoid groove. The medial pterygoid elevates and protrudes the mandible.

The medial and lateral pterygoid muscles, acting together and in concert with the contralateral pterygoid muscles, are responsible for the rotation and grinding motion of the jaws.

All the muscles of mastication are innervated by the motor part of the mandibular branch of the Trigeminal nerve.

2.3.7 Muscles of Facial Expression (Figs. 46-52)

The muscles of facial expression include the muscles of the scalp, the outer ear, the eyes, and the nose. They are for the most part small, subcutaneous muscles that form the sphincters of the eyes and mouth and, by wrinkling the skin, cause various facial expressions. Many of these muscles have no bony attachments but arise and insert into skin or other muscles.

All the muscles of facial expression receive nerve innervation via the Facial nerve, and as Fried (1976) points out (which has some bearing on this study), a characteristic of these muscles is their wide variation in size, shape, and strength. They also work synergistically and not independently, interweaving with one another and making it difficult to separate the boundaries between the various muscles. Their terminal ends are interlaced with each other. Furthermore, there seems to be a minimum of agreement amongst descriptive anatomists regarding the nomenclature and grouping of these muscles. For the sake of brevity, and to emphasise the muscles more relevant to this discussion, the following muscles are mentioned.

Orbicularis Oris: The fibres of this muscle form the lips and encircle the mouth. Some fibres originate from the alveolar processes of the maxilla and mandible and insert into the substance of the lip (Riviere, 1983). However, many of the fibres of the orbicularis come from the other muscles that insert on the mouth. The muscle closes and protrudes the lips and shapes them during speech.

Buccinator: This muscle forms the substance of the cheek. It arises from the alveolar processes of the maxilla and mandible and the pterygomandibular raphe. The pterygomandibular raphe is a group of connective tissue fibres stretching from the pterygoid hamulus to the posterior end of the mylohyoid line of the mandible. The buccinator inserts into, and blends with,

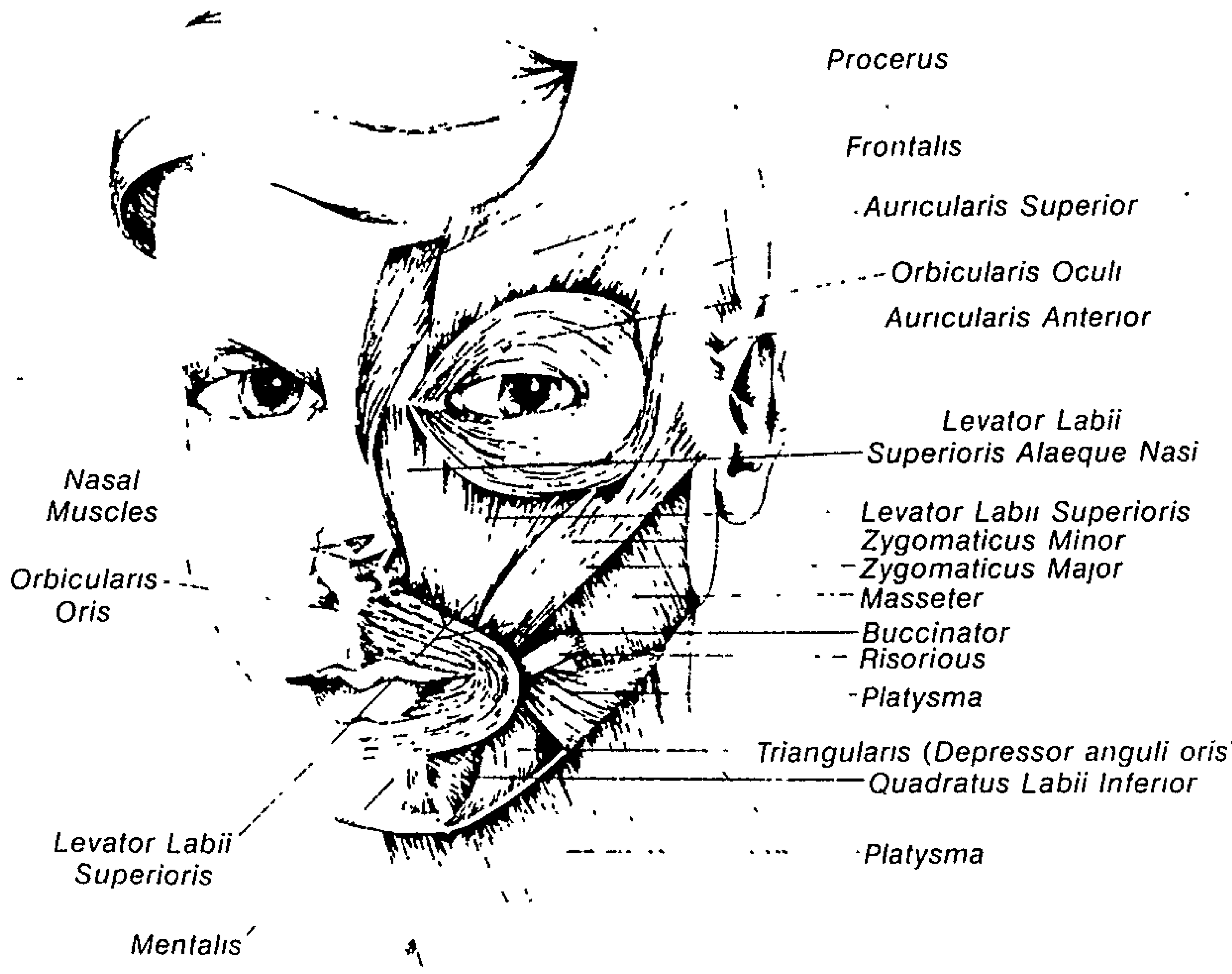


Fig. 46 Muscles of facial expression. (Fried, 1976)

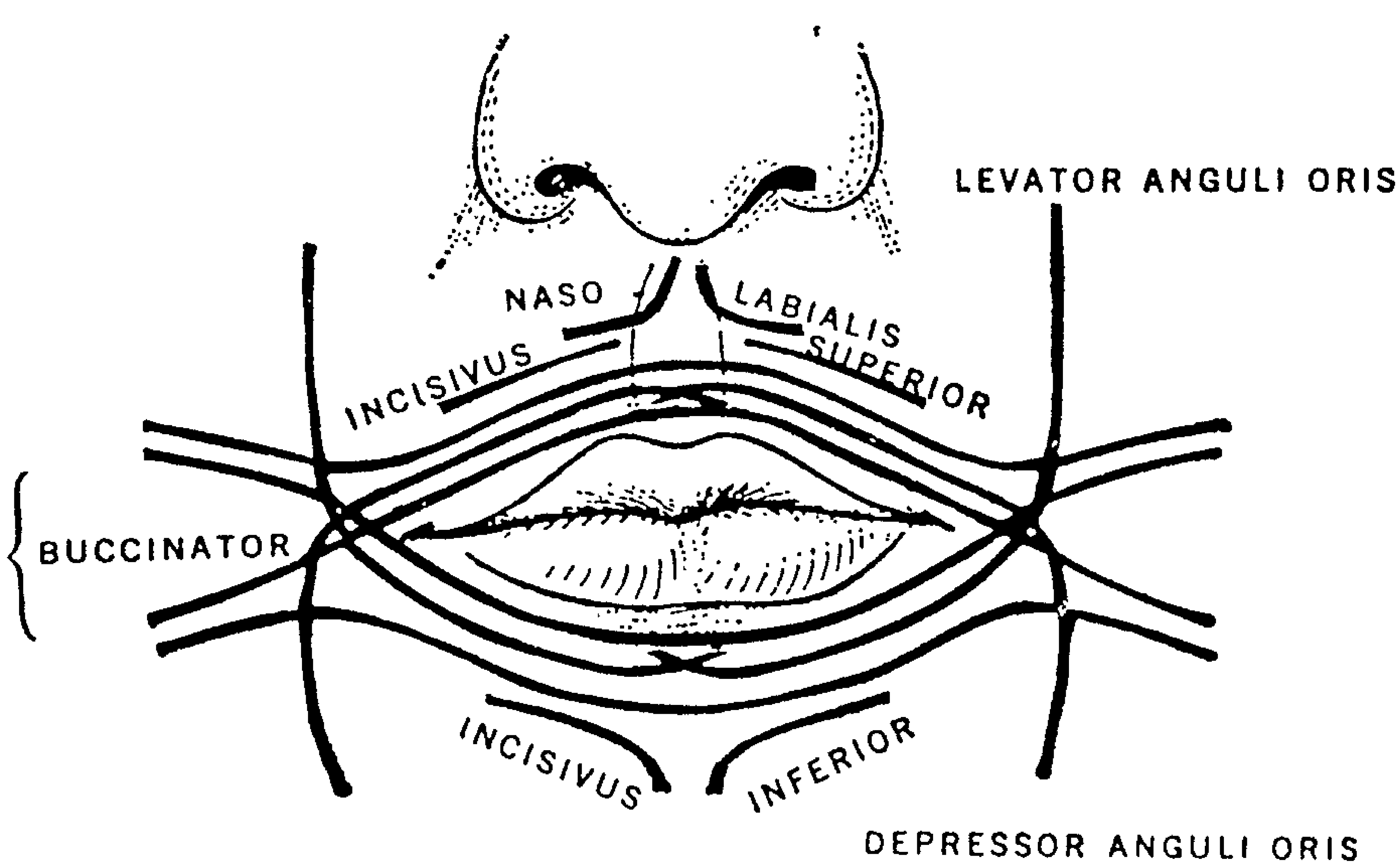


Fig. 47 Orbicularis oris: arrangement of fibres. (Fried, 1976)

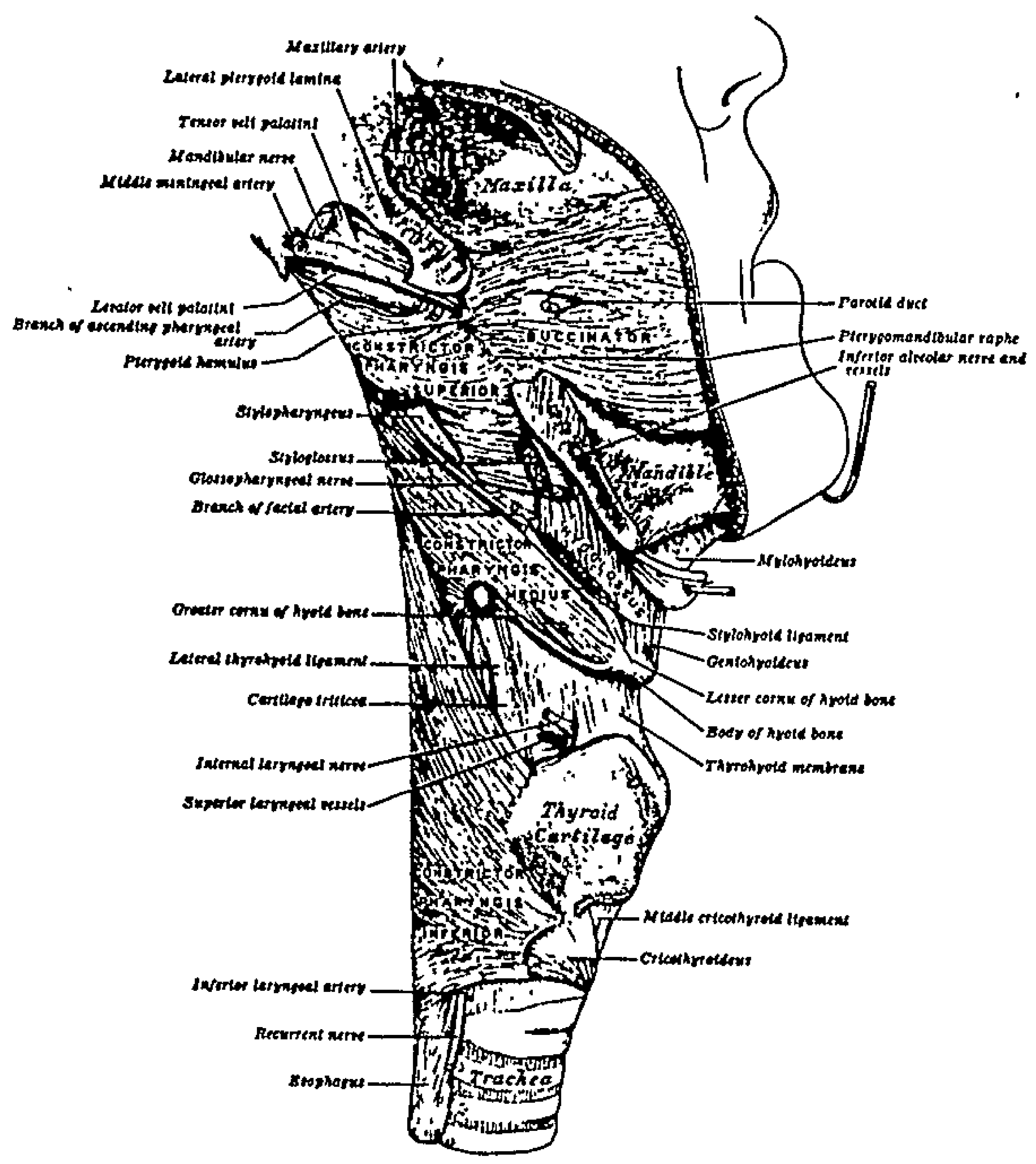


Fig. 48 Buccinator and pharyngeal muscles. (Fried, 1976)

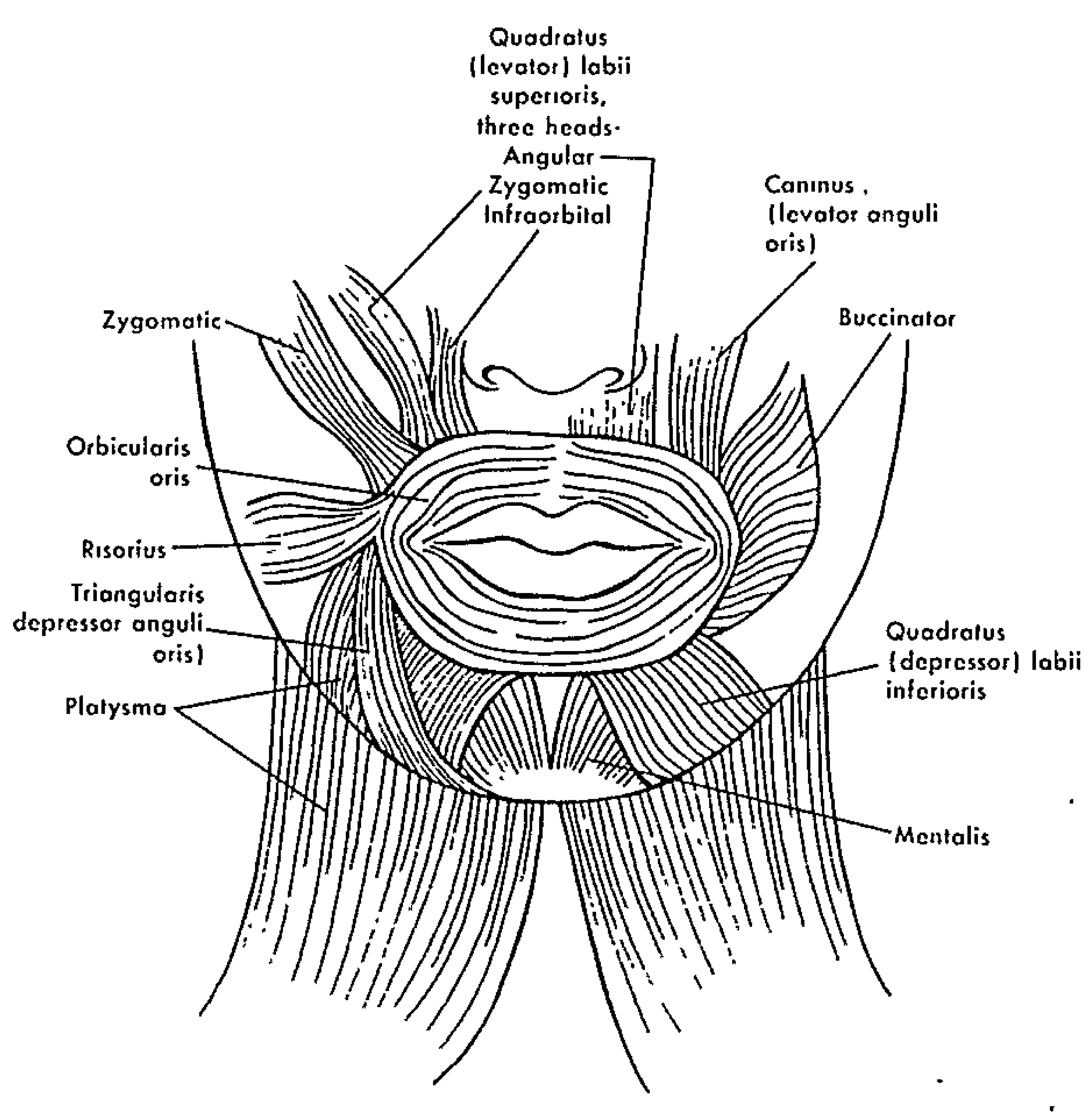


Fig. 49 Muscles of facial expression: lower face. (Barrett and Hanson, 1978)

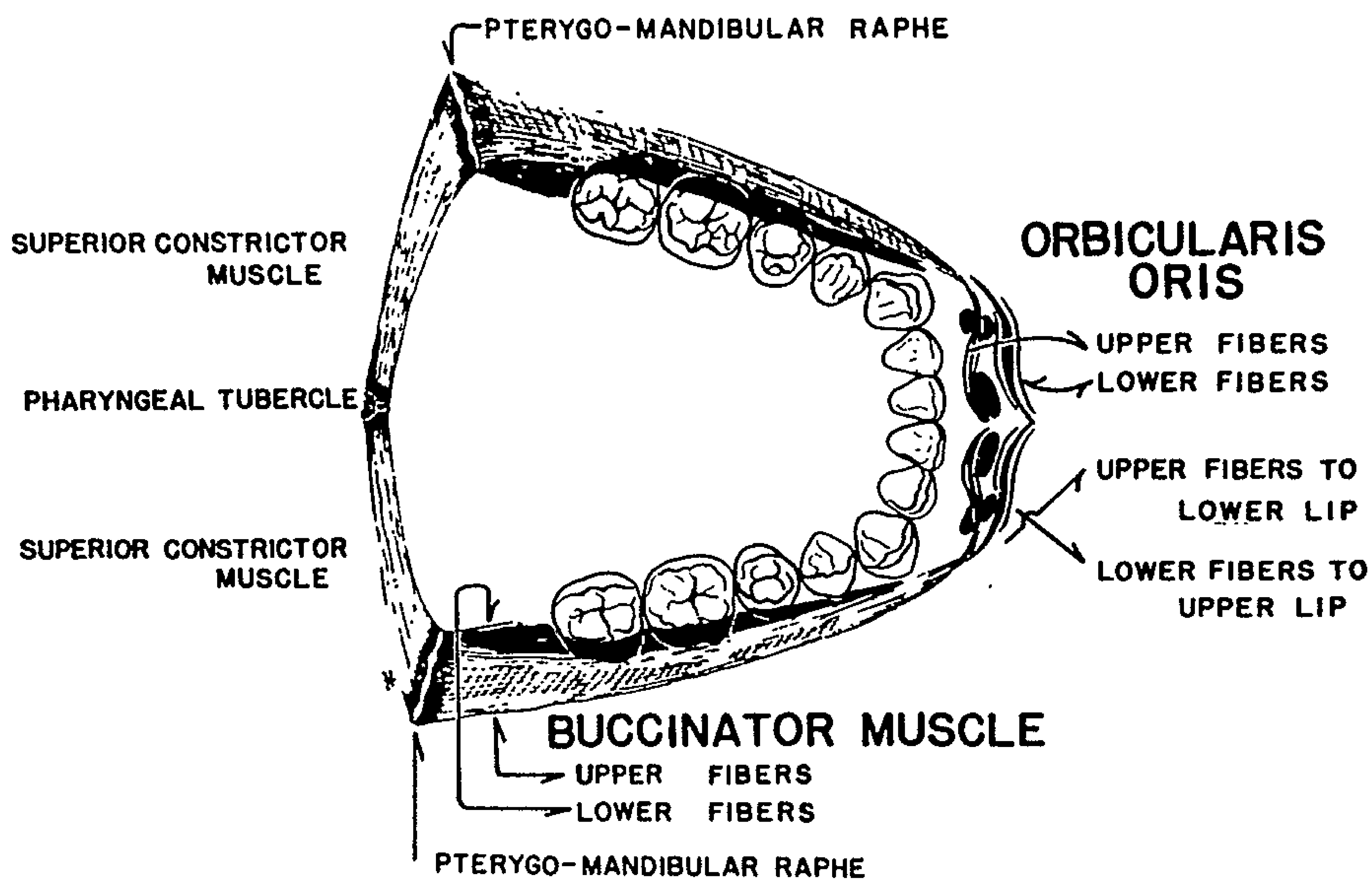


Fig. 50 The buccinator mechanism: continuous band of muscle encircling the dentition and anchored at the pharyngeal tubercle. (Graber, 1972)

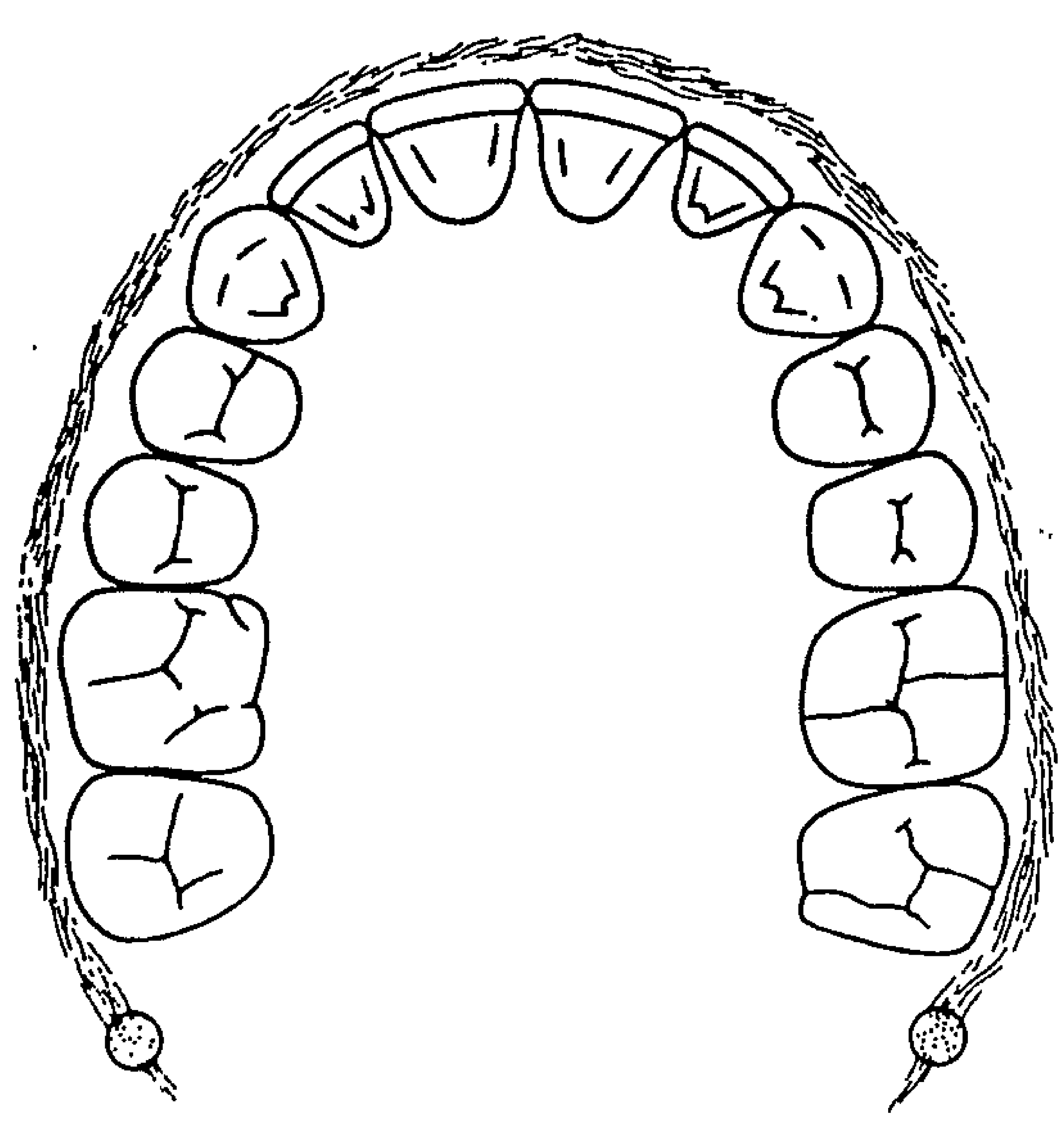


Fig. 51 Dental arch form is controlled buccally by the buccinator and lips, which form a continuous band enveloping the teeth. (Thurow, 1977)

the orbicularis oris at the corner of the mouth. These fibres are a major portion of the substance of the lips. If the buccinator attachments are followed past the pterygomandibular raphe to the pharyngeal tubercle the "buccinator mechanism" becomes evident (Figs. 50, 51). Graber and Weinstein (1958) described this as a system of muscles consisting of the orbicularis oris, buccinator, the pterygo-mandibular raphe, and superior constrictor muscle of the pharynx. The buccinator muscles thereby surround the dental arches, having as their support the pharyngeal structures. The buccinator compresses the cheek against the teeth, keeping food between the teeth during chewing. It also retracts and raises the angle of the mouth.

Mentalis: According to Wilson (1975) the mentalis muscle arises from the mental region of the mandible below the incisor teeth but opposite the roots of these teeth. Its fibres run anteriorly, inferiorly, and laterally, dispersing to be inserted into the integument of the skin over the chin.

The function of the muscle is to compress the skin of the chin against the front of the mandible and to raise it upwards. Contraction of the muscle has no direct effect on the lower incisors. However, it has an indirect effect on the lower lip, the final position of which depends upon the behaviour of the other circumoral muscles acting in conjunction with the mentalis. Generally, the lower lip is forced upwards and can have a marked influence on the incisors. Simpson (1976), more significantly, has found that mentalis activity acts to create lip seal by pushing the lower lip upwards. According to Barrett and Hanson (1978) this muscle, even when not overdeveloped, varies in size more than any of the other facial muscles.

Levator Labii Superioris Alaeque Nasi: This small muscle arises from the frontal process of the maxilla. It divides into a portion that inserts on the ala of the nose and a portion that inserts into the upper lip. It elevates the lip and dilates the nares.

Levator Labii Superioris: This muscle lies lateral to the levator labii superioris alaeque nasi. Its fibres extend from the orbital rim above the infraorbital foramen to the upper lip. It elevates the lip.

Levator Anguli Oris: Also referred to as the Caninus, it is the only muscle in the deep layer of muscles that opens the lips. It arises from the canine fossa just below the infraorbital foramen and inserts into the angle of the mouth, which it elevates.

Zygomaticus Major and Minor: The muscles both arise from the zygoma, the minor at the maxillary suture and the major more laterally. The minor muscle inserts on the upper lip lateral to the alaeque nasi muscle insertion. The major muscle ends at the corner of the mouth. Zygomaticus minor elevates the upper lip, while zygomaticus major elevates the corner of the mouth.

Risorius: This is a very small muscle arising from the fascia over the buccinator and inserting at the corner of the mouth. It compresses the cheek and pulls the angle of the mouth laterally.

Depressor Anguli Oris: This muscle originates from the external oblique line of the mandible deep to the depressor anguli oris. It inserts into the orbicularis oris and the lower lip, which it depresses.

Platysma: This is a very thin sheet of muscle that begins in the fascia of the shoulder and upper chest. The fibres pass superiorly and insert on the inferior border of the mandible and muscles and skin of the mouth and lower face. It draws the outer part of the mouth and skin of the chin downward as in a pout.

Modiolus (Fig. 52): Described by Jacobs and Brodie (1966b) as "a complex interlacing of muscle bundles at the corner of the mouth"

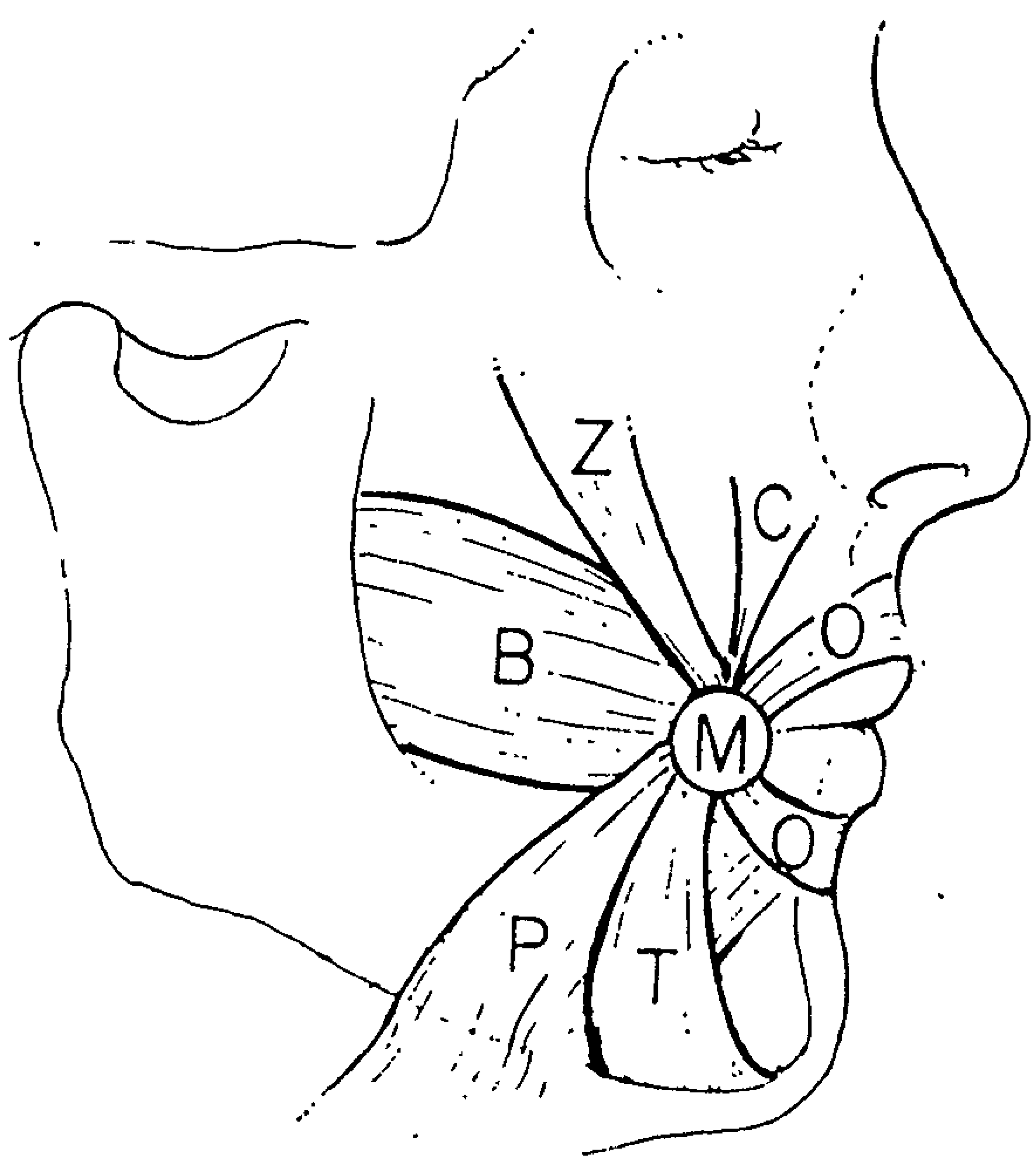


Fig. 52 Muscular modiolar configuration. B, buccinator; Z, zygomaticus major; C, caninus (m. levator anguli oris); O, orbicularis oris; T, triangularis (m. depressor anguli oris); P, platysma-risorius complex; and M, modiolus. (Jacobs and Brodie, 1966b)

this group of muscles is included because of its anatomic significance in integrating the muscles of facial expression. There are six muscles entering into the formation of the "modiolus" as Lightoller (1925) named it. These six muscles form a thick mass of muscle lying just outside the angle of the mouth. The six are the zygomaticus major, the levator anguli oris, the depressor anguli oris, the platysma-risorius complex, the orbicularis oris, and the buccinator. Lightoller considered this area to be of the greatest anatomic and physiologic importance and viewed its strength and position as dominant factors in regulating the precision of cheek and lip movements. Similar conclusions have been stated by others (Huber, 1931; Rosenblum, 1963; Gould and Picton, 1964; and Scott, 1944).

This completes the description of the orofacial, lingual, velonaso-pharyngeal, and linguo-cervical musculature. It must be stressed that in order to appreciate the role of the muscles at rest and in function, a more than cursory appreciation of these muscles is required. In addition, it would seem that a great deal more work is required in this field before an adequate understanding will be reached. With so much diversification in the various authors' points of view, areas of conjecture, and plain lack of understanding, it seems almost an anachronism in this day and age; the science of anatomy having been in existence for at least the last 450 years, since Leonardo da Vinci (1489) and the thorough scientific dissections by Versalius (1543), and well before that to the early Romans, Greeks, and Egyptians (Robinson, 1943; Poynter and Keele, 1961; Singer and Underwood, 1962). I have attempted therefore, in this section, to not only enhance the understanding of oral and paraoral musculature, but also to indicate to the clinician where complications of description and understanding still exist.

2.4 Process, Muscular Activity, and Initiation of Swallowing

> "Nor is this for any other reason than it is in a piece of machinery, in which, though one wheel gives motion to another, yet all the wheels seem to move simultaneously, or in that mechanical contrivance which is adapted to firearms, where the trigger being touched, down comes the flint, strikes against the steel, elicits a spark, which the flame extends, enters the barrel, causes the explosion, propels the ball, and the mark is attained - all of which incidents, by reason of the celerity with which they happen, seem to take place in the twinkling of an eye. So also in deglutition: by the elevation of the root of the tongue and the compression of the mouth the food or drink is pushed into the fauces, the larynx is closed by its own muscles and the epiglottis, whilst the pharynx, raised and opened by its muscles no otherwise than is a sac that is to be filled, is lifted up, and its mouth dilated; upon which, the mouthful being received, it is forced downwards by the transverse muscles, and then carried farther by the longitudinal ones. Yet all these motions, though executed by different and distinct organs, perform harmoniously, and in such order, that they seem to constitute but a single motion and act, which we call deglutition."
>
> William Harvey, 1628 (Quoted by Doty, 1968)

These observations and this description of the process of deglutition made over three hundred and fifty years ago bear a remarkable accuracy to the process as we know it today. According to Doty (1968) Harvey's portrayal emphasises "with art and accuracy" both the extraordinary complexity and the automatic coordination characteristic of the act of swallowing.

Let us now examine the swallowing act more closely.

2.4.1 Process of Normal Swallowing

There are various ways of considering normal or typical swallowing behaviour. One way is to view it in terms of the stages involved, with various authors describing it in a number of stages ranging from two (Haas, 1977) to four (Fletcher, 1970) and even five (Subtelny, 1970). Another way is to view it in terms of the consistency and size of material being swallowed (Du Brul, 1980), the point being that solids and liquids evoke different swallowing patterns. Yet another way is to view swallowing in terms of maturation (Moyers, 1964). In this way swallowing behaviour is seen to differ during the various ages and stages of maturation of the individual. All these areas will be examined. At this point, however, the various stages of swallowing allow some scope for examination of normal behaviour.

Magendie (1822) was the first to simplify the study of the complexities in the swallowing mechanism by dividing the act into three stages (Fig.53):

(1) oral,

(2) pharyngeal, and

(3) oesophageal.

Other early workers in this field, mentioned by Straub (1951), were Kronecker and Falk (1880) who studied the second stage in depth, and Cannon (1898, 1900) who studied differences in swallowing for liquids and solids or semi-solids.

Hiiemae, Thexton, and Crompton (1978) mention the little known radiographic study by Mosher (1927). Using himself as a subject in the early days of radiography, he was able to give a detailed description of the movements of the back of the tongue and larynx.

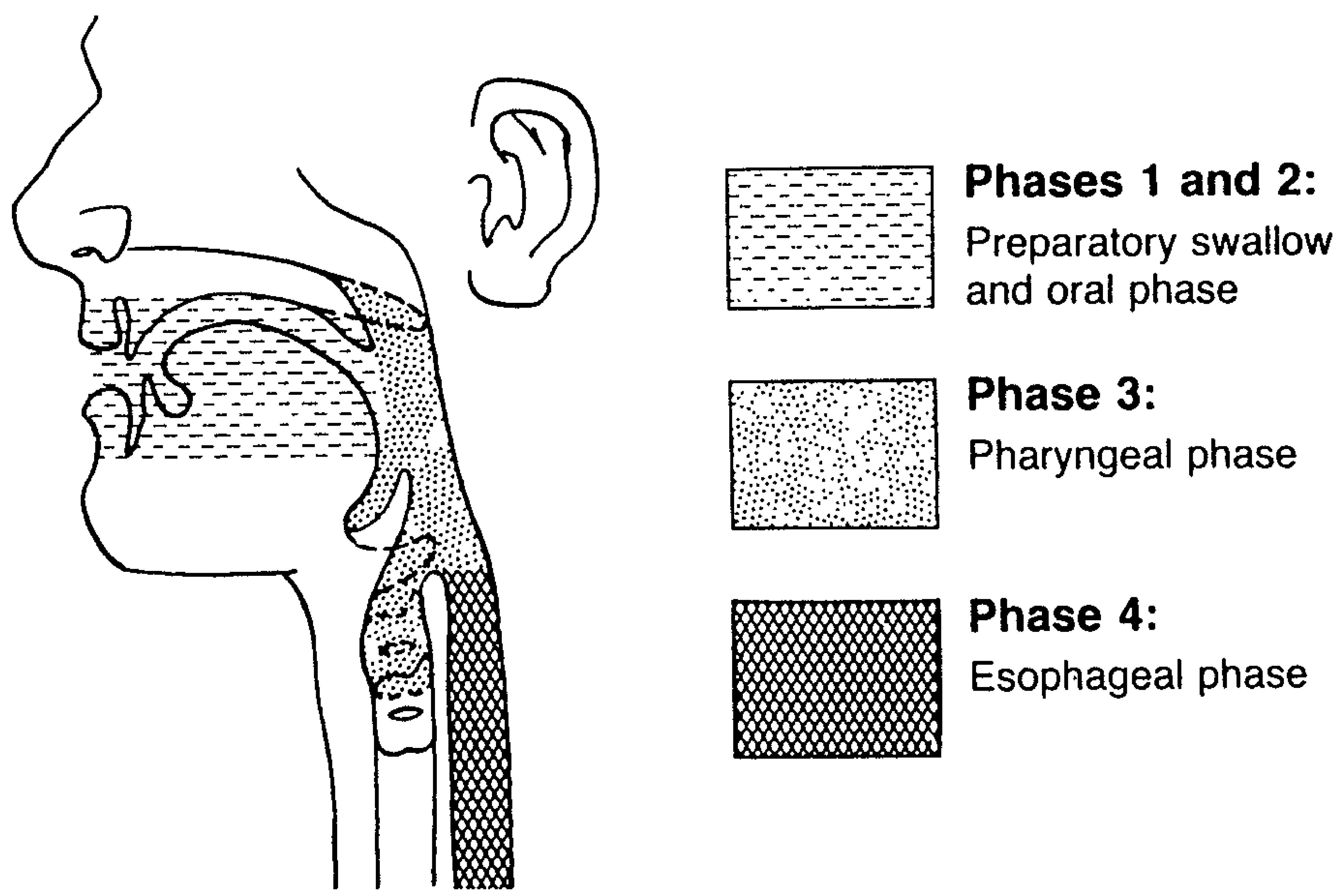


Fig. 53 Four phases of deglutition: anatomical sites. (Pierce, 1978)

Following the work of Barclay (1930, 1936) and Johnstone (1942), the movements of the tongue in swallowing were studied by Whillis (1946) who was able to view the tongue directly and record the movements with slow-motion cinematography. The subject had a wide gap in the left cheek and was edentulous which allowed direct vision of tongue movements. Fluids and solids were swallowed. He found that in swallowing fluids, two phases were seen. In phase 1, the intrinsic muscles were used to squirt the fluid through the mouth. In phase 2, contraction of the mylohyoid muscle bulges the base of the tongue into the oral pharynx. For solids, only phase 2 was used except when the mouth was being cleared of saliva and debris after the bolus had been swallowed.

In 1937, Truesdell and Truesdell published an article on deglutition. This followed fifteen years of study and, following Magendie's three stages, deglutition was described in detail with particular emphasis on the second stage. In summary the process was described this way:

Stage 1. Voluntary and conscious; food is collected into a bolus and carried to the isthmus of the fauces.

Stage 2. Involuntary but conscious; a reflex mechanism, the bolus is carried through the oral and laryngeal portions of the pharynx.

Stage 3. Involuntary and unconscious; the bolus is carried through the oesophagus.

These authors described at length the physiology of the mechanism and summarised by saying that in the process of deglutition there is a collection of the bolus, the closure of the internal auditory tubes, the passage of the bolus past these openings, and the clearance of the respiratory passages for normal respiration after deglutition is completed.

Strang (1943) also used the three stages in describing, in great detail, the swallowing process. In a critical account of Strang's descriptions, Rogers (1961) points out that Strang's description indicates that swallowing is an extremely complex function, with most of Stage II and all of Stage III being involuntary reflexes.

Ardran and Kemp (1951) in the first of their many radiographic studies of swallowing, described how the bolus is expressed into the pharynx by a squeezing action of the tongue against the palate. In 1955, Ardran and Kemp again reported on swallowing behaviour with various types of bolus (fluids, large and small mouthfuls; food, drink; sucking and drinking; paste and solid lumps). They generally confirmed the findings of their previous study and others, but also found no evidence of negative pressure in the pharynx. Their findings suggested that in most normal subjects the bolus descends into the pharynx while it still contains air and before the larynx closes.

The work of Rushmer and Hendron (1951), as quoted by Davenport (1977), gives a vivid account of the basic swallowing process (Fig.54). Yip and Cleall (1971) give a similar illustrative view of swallowing (Fig.55) though with a slightly simpler approach. The stages are divided into four main activities of the tongue, soft palate and hyoid bone. Roth and Calmes (1981) also give an adequate and brief account of swallowing movements. They mention that swallowing is a triggered, all-or-none sequence of movements. Once it is initiated, the bolus having reached the oropharynx, it goes to completion and, apart from exceptional circumstances, the sequenced event cannot be interrupted. Again they divide the sequence into three phases:

<u>Oral Phase</u>: The oral phase involves the formation of the food or liquid bolus and expulsion of the bolus from the oral cavity into the pharynx.

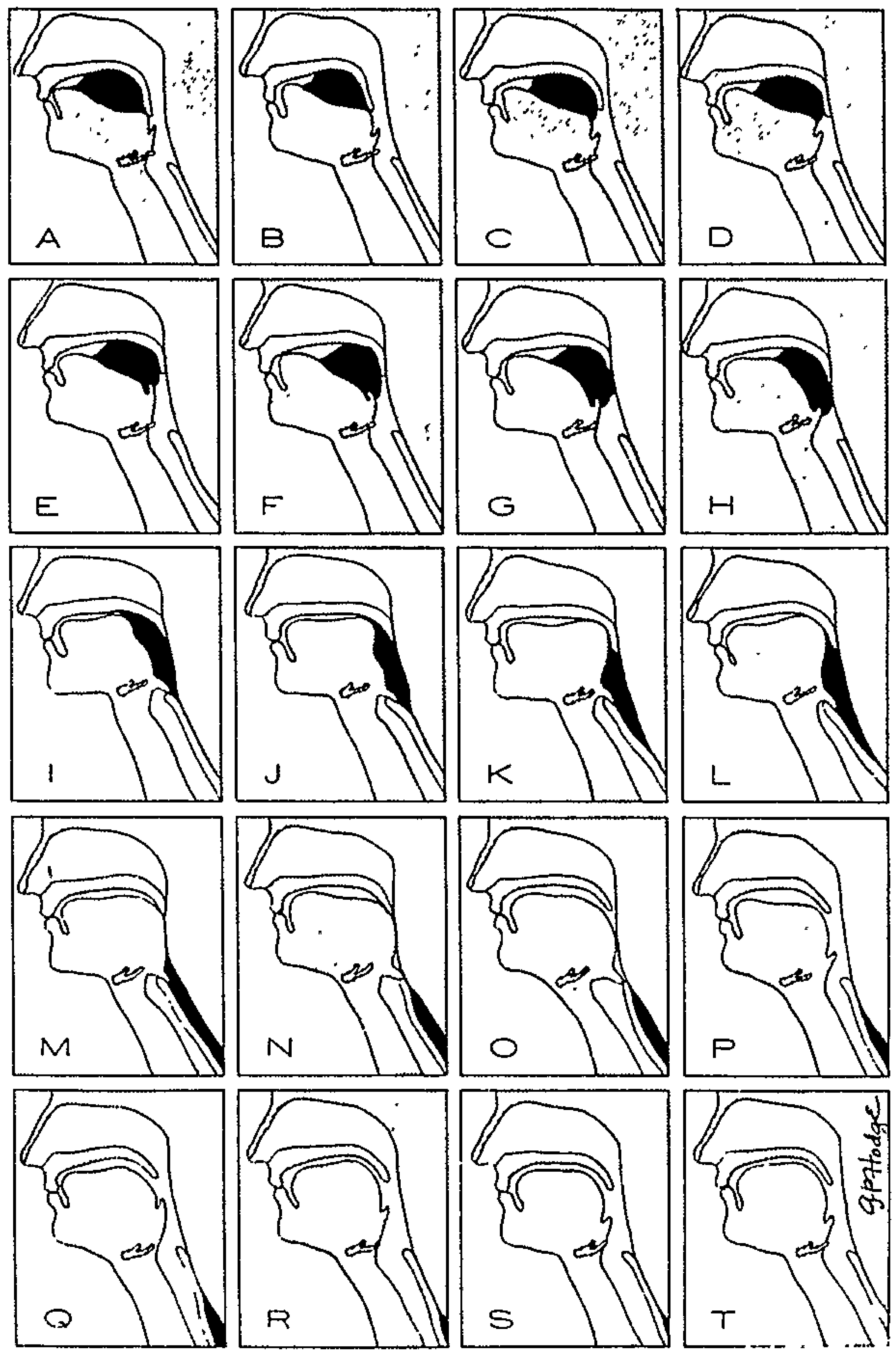


Fig. 54 Sequence of events during swallowing. A and B, the soft palate forms a partition extending to the base of the tongue; C, D, E and F, the soft palate is elevated to obstruct the nasopharynx as the bolus moves backward over the tongue; G, H and I, the bolus tilts the epiglottis backward; from H to R the glottis, not shown, cuts off the laryngeal airway; J and K, the bolus passes smoothly over the convex epiglottis, and the tongue moves backward as a piston; K, the bolus is slightly delayed at the hypopharyngeal sphincter; O and P, the soft palate relaxes, and the epiglottis ascends; Q-T, the bolus moves down the oesophagus. the entire sequence occupies one and a third seconds. (Davenport, 1977)

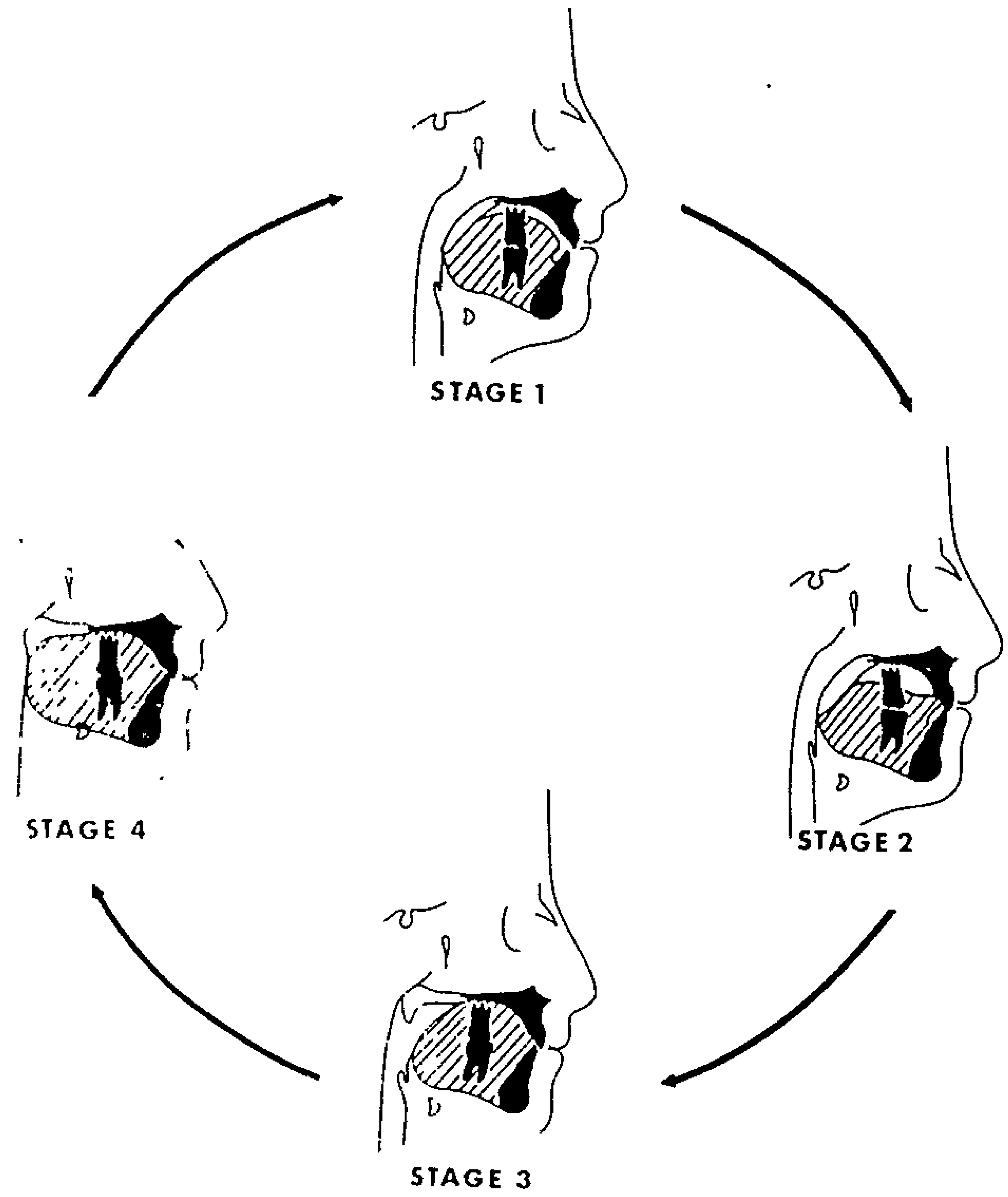


Fig. 55 Diagrammatic illustration of the frames selected for cinefluorographic analysis of deglutition. Stage 1 represents the rest position. Stage 2 is the stage when the tongue tip has moved forward to contact the upper incisors or the palatal mucosa. Stage 3 is the stage when the dorsum of the tongue has reached the junction of the hard and soft palate. Stage 4 is the stage when the hyoid bone has reached its higher and most forward position. (Yip and Cleall, 1971)

PRESSURE GRADIENT	
Tongue: piston action	
Stabilization of tongue base	Muscles in floor of mouth Facial muscles Levator muscles
Pharyngeal constrictors: stripping action	
Esophagus: peristalsis	
PREVENTION OF REFLUX	
Anterior oral seal	Lips Incisors Tongue
Tongue/palate apposition	
Tongue/pharyngeal wall apposition	
Hypopharyngeal sphincter	
Gastroesophageal sphincter	
PROTECTION OF AIRWAY	
Palate/pharyngeal wall apposition	
Elevation of larynx	
Adduction of vocal folds	
Apnea	

Fig. 56 Table: Requirements of alimentary swallow. (Dubner, Sessle and Storey, 1978)

The tongue base is first stabilised by the muscles in the floor of the mouth and by the jaw-closing, and possibly facial, musculature. The tongue then rises to contact the hard palate and squeeze the bolus into the pharynx by a piston-like action. During the oral phase the soft palate also rises to contact the posterior pharyngeal wall and thereby seal off the nasal cavity; the characteristic elevation of the larynx and cessation of respiration are also initiated.

Pharyngeal Phase: In the pharyngeal phase the posterior portion of the tongue comes into close apposition with the posterior pharyngeal wall and the bolus is propelled toward the oesophagus by the sequential stripping action of the pharyngeal constrictor muscles. In advance of the bolus, the upper oesophageal (hypopharyngeal) sphincter relaxes, and the epiglottis is elevated and tipped over to protect the airway. The bolus flows around the epiglottis and enters the oesophagus through the relaxed sphincter. Any bolus residue that might pass through the guard of the tipped epiglottis is prevented from further entry into the larynx by the approximation of the vocal folds; it can subsequently be expelled by coughing.

Oesophageal Phase: In the oesophageal phase, peristalsis carries the bolus to the relaxed oesophageal (gastro-oesophageal) sphincter and into the stomach. Regurgitation or reflux from the stomach into the oesophagus, or from the oesophagus into the pharynx, is prevented by the contraction of the lower and upper oesophageal sphincters.

According to Dubner, Sessle, and Storey (1978) (Fig.56) and supported by Roth and Calmes (1981) the alimentary swallow appears to have three requirements. Firstly, the sequential contractions of the various muscles provide the pressure gradient that propels the bolus into the stomach. The relaxation of the upper oesophageal sphincter allows the high pharyngeal pressure developed to push the bolus into the oesophagus, while the subsequent sphincter contraction and pressure developed there helps to prevent reflux. Through peristaltic contraction, the pressure wave then continues down the oesophagus to the lower oesophageal sphincter. This sphincter, like its distal counterpart, also relaxes and then contracts, allowing the passage of the bolus and then preventing its reflux. The propulsion of the bolus through the pharynx and oesophagus is aided by gravity.

The second feature is <u>containment of the bolus</u> and prevention of reflux. The containment is effected in the front of the mouth by contact of lips, overbite of incisors, or tongue thrusting into an open bite. Prevention of reflux is achieved by the apposition of the tongue, first against the palate, and then with the posterior pharyngeal wall. This is followed by contraction of the hypopharyngeal sphincter, and then the gastro-oesophageal sphincter following initial relaxation.

The third requirement of swallowing is <u>protection of the airway</u>. The soft palate and pharyngeal wall apposition protects the nasal airway. Apnea occurs almost from the commencement of the act, thus preventing inspiration of part of the bolus. The lower airway is protected by the elevation of the larynx and the tipping of its epiglottis and by vocal fold adduction.

There have been many accounts of swallowing in the literature in recent times, most with similar descriptions but with slight variations of emphasis and investigation.

Ballard (1953) quotes the work of Rix (1946, 1953) who found that in the normal swallowing pattern in the adult the mandible is fixed in a position which brings the teeth into light occlusion, the tongue is elevated by a contraction of the mylohoid muscles, and a peristaltic wave passes along the tongue which begins as a contact of the tip of the tongue with the roof of the mouth behind the upper incisors.

Gwynne-Evans (1954) suggested that there were two broad types of swallowing behaviour with many variants between. The first he called the "somatic" type and the second the "visceral" type according to the division of the muscles involved. The premise was that there is an anatomic distincion between the somatic muscles, those attached to the body wall, and visceral muscles, those attached to the intestines and other visceral structures. In somatic swallowing, he said there is evidence of selective action among the oral muscles which allows the contraction of the masseter and temporal muscles to bring the teeth firmly together while the lips and the cheeks are left in a relatively passive state. In the visceral type, the teeth are not brought together and the orbicularis oris and circumoral muscles exhibit a sphincteric or peristaltic form of behaviour as the muscles of the floor of the mouth and tongue contract to squeeze food, and noticeably saliva, backwards toward the pharynx. He suggested that the visceral type was a more basic or infantile pattern of swallowing aimed at simple survival, normal in the very young and expected to modify and gradually disappear with growth and development of the child. Gwynne-Evans and Tulley (1956), however, found that the visceral type does not always disappear, and may remain into adult life.

Winders (1958) measured the forces exerted on the dentition by the perioral and lingual muscles during swallowing. He found that the perioral muscles do not normally contract during swallowing in subjects with excellent dentitions. He also deduced that subjects in which a Class II occlusal or skeletal relation existed, and who could form an anterior seal when the teeth were occluded, did not contract the perioral musculature during swallowing.

He found that the perioral muscles contracted only when the dentition could not seal itself, that is in cases of anterior open bite or lack of anterior overbite with accompanying anteroposterior skeletal dysplasia.

Rosenblum (1963a and b), however, in studying orofacial muscle activity during deglutition using physiographic cinematography, found that orofacial muscle activity was more common. He compared two groups, one with severe malocclusion and the other with acceptable dental occlusions, and contrasted the magnitude, duration, and incidence of activity in the modiolus and mentalis muscle areas and also on the general incidence of orofacial activity. He found "some form of orofacial activity" in 93 per cent of those with "distoclusion" and in 65 per cent of those with "normal" occlusion.

Cleall (1965) studied swallowing cinefluorographically, and determined five stages of deglutition (Fig.57). He also found that there were exceptions to the "teeth together" swallow in the group of normal subjects, which added another recorded variation to the normal swallowing pattern.

Bosma (1957) also described a variation from the accepted. He divided the process of swallowing according to the route of the bolus and found four stages. He cited two earlier little known authors, Heuermann (1753) and Haller (1762) who described swallowing behaviour to be similar to that of Magendie (1817).

Abrams (1963) used miniature electronic pressure measuring devices and compared swallowing records for water, pudding and saliva. He found a consistent pattern of swallowing:

(1) formation of a lateral seal and then an anterior seal;

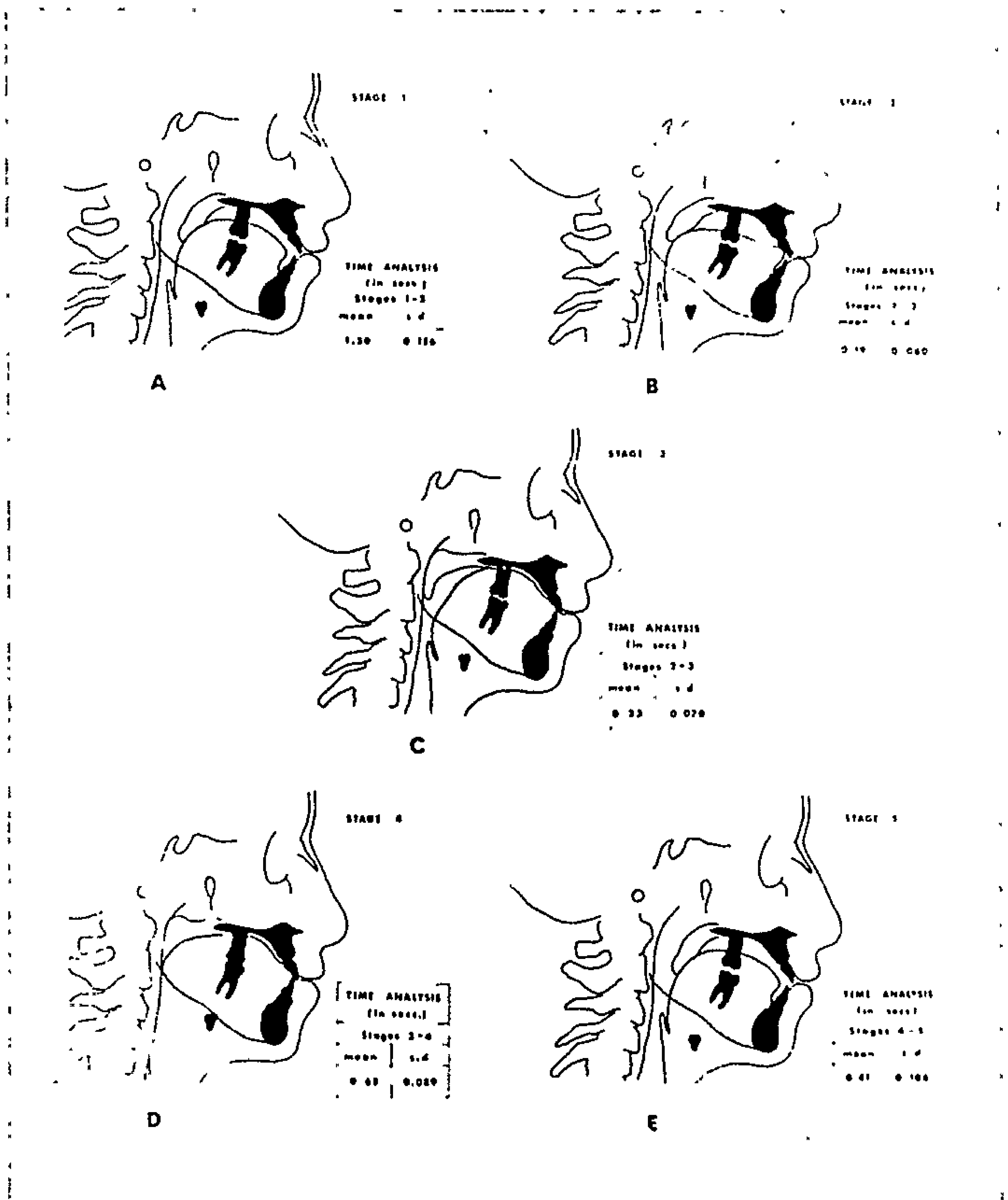


Fig. 57 Tongue movements in swallowing. A, initial rest position. B, tongue tip elevation. C, dorsum movement reaching the junction of the hard and soft palates. D, maximum superior and anterior hyoid position. E, final rest position. (Cleall, 1965)

(2) development of rolling contact towards the height of the palate, culminating in the application of maximum pressure simultaneously throughout the surface of the palate;

(3) maintenance of contact pressure after oral clearance; and, finally,

(4) bracing against the palate in pharyngeal clearance.

Straub (1960) comprehensively reviewed the literature and described the normal swallowing process as was "generally accepted".

Ricketts (1968) described his thoughts on how a normal swallow should proceed. He said that under normal circumstances, the teeth should remain closed during deglutition as the mandible is fixed or braced via the teeth for active swallowing. The tongue contacts a broad surface from the lingual aspect of the lower incisors to the cingulum of the upper incisors and up the rugae of the palate. A wave of contact travels the length of the palate as the bolus is squeezed into the pharynx in the act of normal swallowing. The hyoid bone (until now rarely mentioned) "moves upward and forward on a smooth arc to a level of the lower border of the mandible, from whence it returns in a smooth arc".

Ardran and Kemp (1967) and Pierce, Soentgen, Brenman, Mackowiak, and Friedman (1969) found that the elevation of the tongue in the oral phase of swallowing has a forward component that allows the tongue to move away from the free end of the epiglottis. In this way the food bolus enters the valleculae and upon contacting the epiglottis is deflected into the lateral food channels on either side of the laryngeal inlet.

Hanson, Hilton, Barnard, and Case (1970) were critical of cinefluorographic techniques following research they had performed to investigate its effectiveness in studying deglutition. They maintained that its main limitation was that the dentition often obscured the anterior portion of the tongue, making it difficult in most cases to determine whether linguodental contact occurs during actual swallows of fluids and solid material.

Subtelny (1970) examined the swallowing sequence using cineradiography, and described his results in terms of five stages of deglutition. In a later paper, Subtelny (1973) expressed his concern that the normal swallowing patterns had not been adequately defined. His studies, however, did not shed any new light on this obscure area; "Not everybody looks alike, not everybody functions alike, nor does everybody swallow alike." He found many variables in normal patterns of deglutition. Molars were found to be apart or together; tongue protrusion was observed as well as no protrusive activity; the same was found to be true of circumoral muscle activity.

In a description of normal swallow Proffit (1977) points out that the tongue contacts the lingual surfaces of the maxillary and mandibular incisors. Although the tongue tip is placed up behind the maxillary incisors, tongue pressure against the mandibular incisors is usually a little higher than it is against the maxillary incisors.

Haas (1977) described deglutition in a most unusual way. He claimed that the normal swallow is two-phase. Firstly, there is the initiation of the swallow. Here the tip of the tongue touches the cinguli of the lower incisor teeth and not the incisive papilla. As the swallow progresses, the dorsum of the tongue rises to touch the palate. In the second stage, the tip "flips up" to start the peristaltic wave and the bolus of food on its way back toward the oropharynx. Having no new source of reference for these observations, they seem to be interesting observations on past studies or possibly introspective observations.

Frankel (1980) paid particular attention to the "labial valve". Its relevance, he wrote, for the establishment of physiological conditions in the orofacial area had been underestimated in the past. He stressed the importance of the postural performance of the muscles providing the anterior oral seal. He cites the work of Eckert-Mobius (1962) who showed the physiological relevance of the anterior valve. He found that after the lips are brought into contact, the tongue comes into proximity with the palate. The peristaltic motion of the tongue causes the air in the oral cavity to be expressed into the pharynx and a vacuum is created. This was described as far back as Auerbach (1888) and studied further by Gwynne-Evans (1948), but not substantiated by Ardran and Kemp's (1951) findings. As suggested by Eckert-Mobius, this vacuum is the essential factor for maintaining the approximation between the palate and the dorsum of the tongue, and is therefore of relevance also for the posterior seal.

More recent studies, moreover, have allowed Walker (1978) to give a comprehensive description of the variations of pressure within the oral cavity and pharynx. He sums up by saying that the basic mechanism of swallowing is the development of pressure gradients by the musculature, so that the bolus can be transported from the oral cavity to the oesophagus.

According to Jenkins (1978) liquids flow down the oesophagus by gravity, ahead of the peristaltic wave, although its entrance into the stomach is held up until the cardiac sphincter opens after the arrival of the peristaltic wave. He also reports the finding that when the body is inverted, the time taken for a solid bolus, from mouth to stomach, is greater than normal.

However, changes of position within the normal range do not have much influence on the time required for swallowing. He concluded that gravity plays little part in swallowing except of liquids.

Jenkins also cites the study of Jones and Work (1961) on the average volumes of fluid swallowed with each act of deglutition. They found the volumes to be: adult females 14ml, adult males 21ml, and children (1.25 to 3.5 years old) 4.5ml.

Frequency of swallowing has been the subject of many studies (Straub, 1961; Subtelny, 1965; Rosenblum, 1963a; Doty, 1968). Flanagan, Lear, and Moorrees (1963) and Lear, Flanagan, and Moorrees (1965) found that previous estimates of swallowing frequency of 2000 to 2400 were too great. They studied fifteen subjects over a 24 hour period. A microphone was placed over the larynx and the noise of swallowing was recorded. They determined that humans swallow, on the average, approximately 590 times daily - 146 times while eating, 394 times while awake but not eating, and 50 times during sleep. Most of the sleep swallows were in the early stages or the later hours of sleep as sleep became increasingly light. They also invariably found that there were periods of 20 minutes or more, during deeper sleep, when deglutition was absent. Roth and Calmes (1981) attribute this incidence during sleep to one of two factors: the marked decrease that occurs in nocturnal salivary flow and the resultant decrease in peripheral stimulation; or a relatively direct effect of the sleep state on the activity of the central neural mechanisms underlying swallowing.

As a further note on frequency of swallowing, Kydd and Neff (1964) surveyed a small number of normal (5) and abnormal (6) swallowers. They showed that the frequency of swallowing was significantly less in abnormal swallowers.

In a cinefluorographic study of Hedges, McLean, and Thompson (1965), the oral and pharyngeal stages of swallowing were divided into another four phases "in an effort to combine simplicity and accuracy when depicting the patterns of tongue movement" (Figs. 58,59,59a). They described:

1. Collection Phase. The liquid bolus was drawn up with a straw and collected on one of two areas (Fig.58). With either method, the bolus was eventually placed on the dorsum of the tongue.

2. Anterior Alveolar Phase (Fig.59a). The initial movement of the swallowing act began with the tongue tip placed on the anterior alveolar ridge just lingual to the maxillary central incisors. The posterior part of the tongue was thereby lowered and its contact with the soft palate was broken; the bolus then moved more posteriorly. At the same time, the lips closed and the upper and lower central incisors came closer together. The time for the movement to take place between phases was approximately 1/5th of a second.

3. Midpalatal Phase (Fig. 59B). The anterior one half of the tongue was pressed against the maxillary alveolar ridge and the anterior half of the hard palate; simultaneously the teeth were placed together in centric relation. This compression forced the bolus more posteriorly on the dorsum and root of the tongue which then sloped downward from the middle of the palate toward the epiglottis. While this occurred, the soft palate was elevated, became triangular in shape, and contacted the posterior pharyngeal wall. Synchronously, they found that Passavant's pad, produced by a forward movement of the posterior pharyngeal surface, contributed to the formation of the seal initiated by elevation of the soft palate. It took about 1/6th of a second to reach this phase.

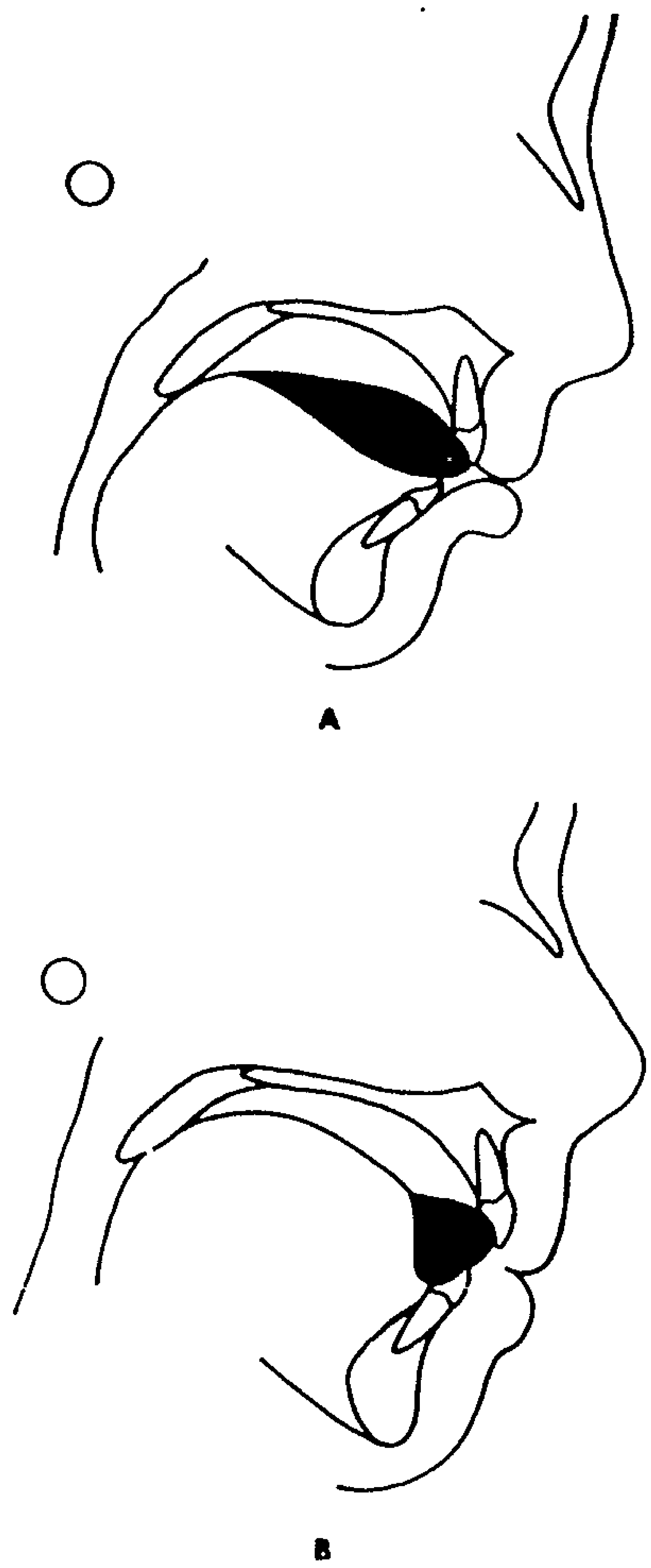


Fig. 58 Collection phase of teeth-together swallow: A. Liquid bolus on the dorsum of the tongue. B. Liquid bolus lingual to the mandibular incisors. (Hedges, McLean, and Thompson, 1965)

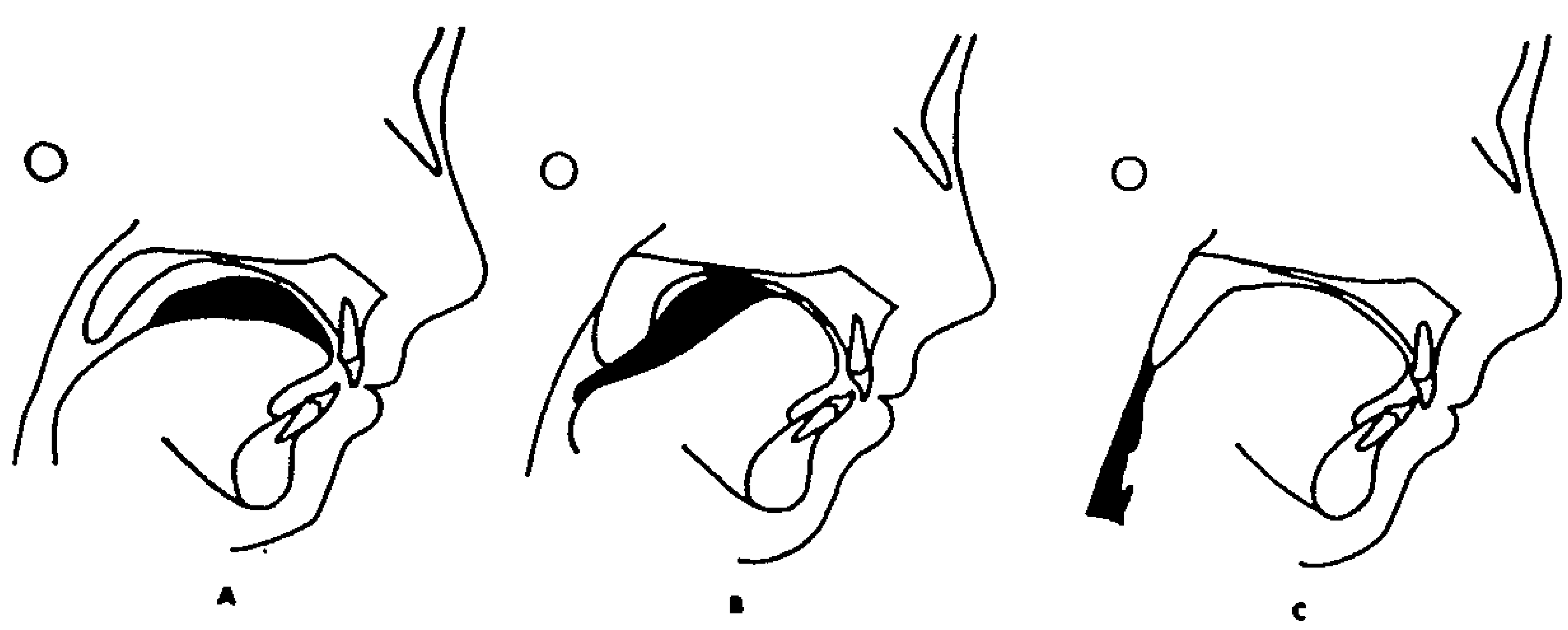


Fig. 3 A. Anterior alveolar phase of teeth-together swallow. B. Midpalatal phase. C. Posterior compression phase.

Fig. 59 A. Anterior alveolar phase of the teeth together swallow. B. Mid-palatal phase. C. Posterior compression phase. (Hedges et al., 1965)

4. Posterior Compression Phase (Fig. 59C). This phase began with the strong contraction of the mylohyoid muscle, indicated by the swift upward and forward movement of the hyoid bone, and ended with the placement of the base of the tongue back against the posterior pharyngeal wall. The bolus was propelled through the entire pharynx and into the oesophagus by this contraction and compression in about 1/10th of a second. The posterior pharyngeal wall continued its wave-like movement from above downward. By this constriction it aided in the movement of the bolus through the pharynx. Simultaneously, by the synergistic action of the infra- and suprahyoid musculature, the larynx rose and was pulled forward under the root of the tongue, and the epiglottis folded down over the laryngeal opening (Fig.59a). This change of position, plus the adduction of the vocal folds and arytenoid cartilages, protected the laryngeal airway and opened the oesophageal orifice. The teeth remained in centric occlusion and no lip movement was discernible up to and including this phase.

The swallow was considered complete when the soft palate returned to its original position. This recovery period varied considerably from one individual to another, but on the average it was approximately $\frac{1}{2}$ of a second. During this recovery period Hedges et al. observed the reinflation of the pharynx. This occurred primarily from the nasal cavity as the soft palate returned to its original position, and then secondarily from the larynx.

There are many other descriptions of normal swallowing in the literature. For the sake of the discussion this description by Hedges et al. (1965) is probably the most applicable, as it concentrates on the areas of interest. One aspect, however, that may require clarification is in the jaw relations as described. In the Midpalatal Phase the teeth were described as being in "centric relation", while in the Posterior Compression Phase they were

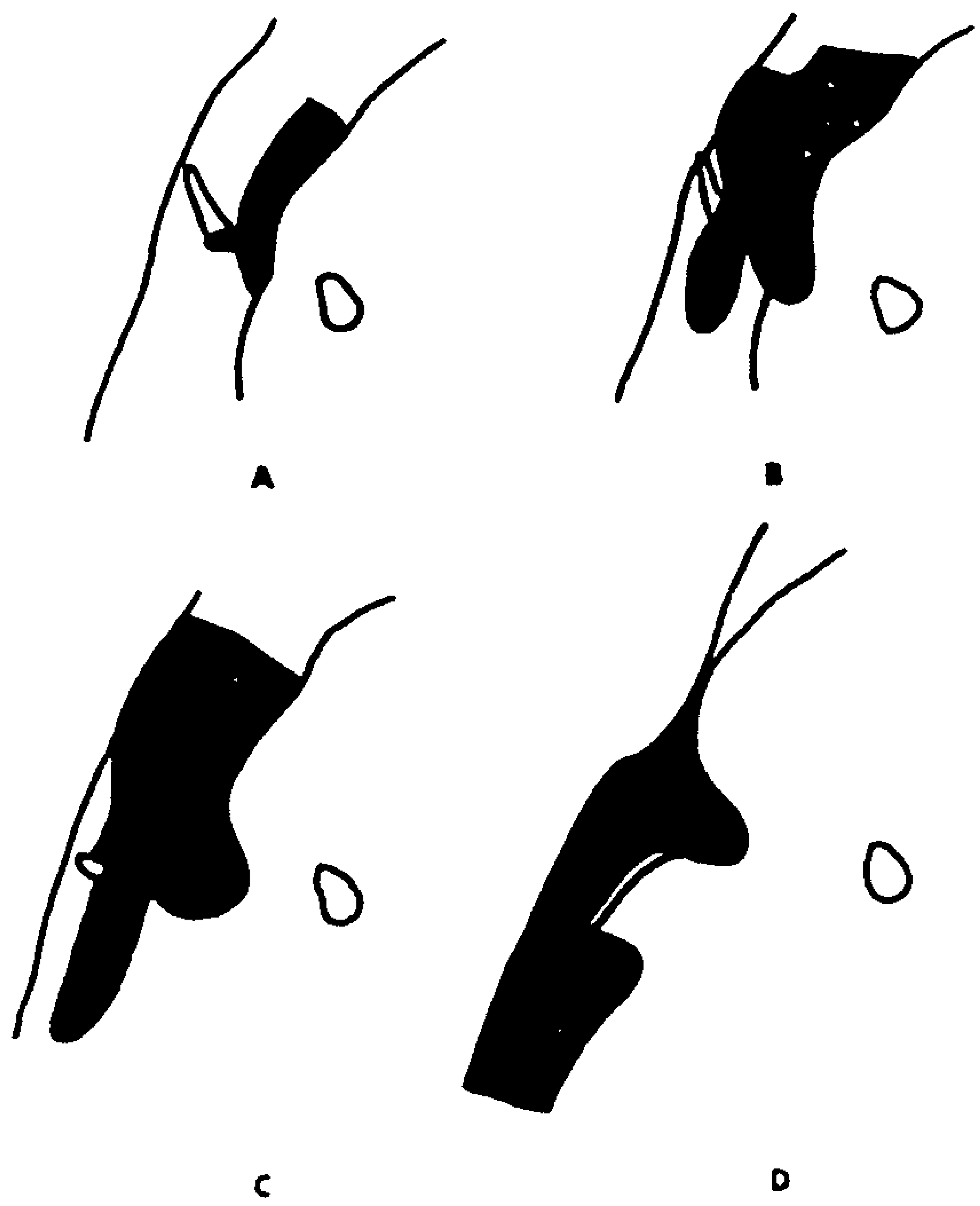


Fig. 59a Action of the epiglottis. Series A to D showing the epiglottis folding backward to cover the larynx as the hyoid bone moves anteriorly. (Hedges et al., 1965)

in "centric occlusion". According to Alem (1976) as quoted by Klineberg (1983), the lower jaw is brought into a stable position by posterior tooth contact to allow swallowing to begin. Tooth contact may be in the intercuspal (IP) or retruded (RP) position but is usually IP as this is usually the contact position that provides best jaw support. Ramfjord and Ash (1983) suggest that occlusal interferences in the path from RP to IP are most significant during swallowing. "Such interferences are important in the occurrence of neuro-muscular disharmony; they may also be significant in the development of traumatic occlusion, both to teeth with premature contacts and to teeth receiving the impact of the slide into centric occlusion."

2.4.2 Muscular Activity During Normal Swallowing

According to Moller (1966) the masticatory muscles contract in the following order during swallowing - firstly the medial pterygoid muscles, then the temporal muscles, and finally the masseter muscles. The mylohyoid and digastric muscles (Cunningham and Basmajian, 1969) contract simultaneously with the temporal muscles, but the strong activity of those muscles, the genioglossus muscle, and the geniohyoid muscle comes about 150msec later. To establish lip seal, the lip muscles start contraction at the same time as the medial pterygoids muscles.

Roth and Calmes (1981) also describe the sequence of movements in a swallow stemming from a temporal (i.e., time-related) sequence of excitation and inhibition that occurs in approximately 30 different muscles bilaterally. Figure (60) illustrates diagrammatically this sequential pattern of activity in a selected sample of muscles involved in the oral and pharyngeal phases of a single swallow; these two phases take up a total time of 0.5 to 1.0 second.

An excellent explanation of this muscle activity is given by Dubner, Sessle, and Storey (1978). The responsible muscles are divided into "obligate muscles" and "facultative muscles". Obligate muscles govern the essential features of swallowing (Fig. 56). They are characterised by a rigid temporal patterning of activity of one muscle relative to the other. These muscles always participate if swallowing occurs. Another feature of these muscles that has been demonstrated is that the temporal sequence during swallowing is insensitive to feedback (Doty, 1968). Once the swallow has begun, all the essential muscles participate in their stereotyped way. These muscles (Fig.60) including the striated musculature of the oesophagus are under the rigid control of a subcortical, brainstem swallowing centre.

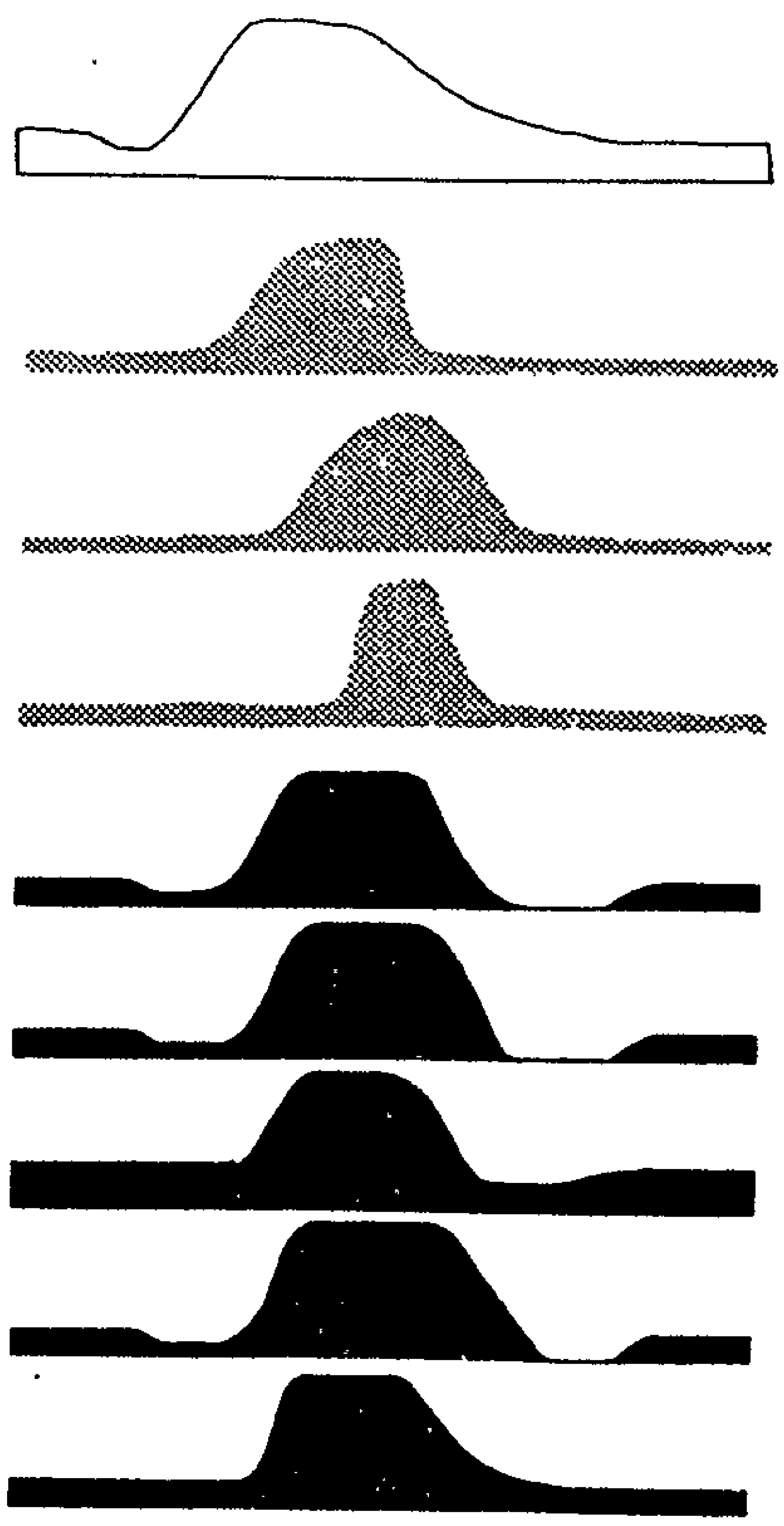


Fig. 60 Electromyographic activity in obligate (dark) and facultative (stippled) muscles during swallowing. The obligate muscles participate rigidly in the synergy, whereas the facultative muscles' participation is variable. Designation of the genioglossus (open) has yet to be determined. (Dubner, Sessle, and Storey, 1978)

Facultative muscles, in contrast to the obligate muscles, participate more loosely in swallowing, which as Dubner et al. (1978) point out, is of particular interest to clinicians. These muscles function to stabilise the tongue base and to establish an anterior oral seal. In contrast to the obligate muscles, the facultative muscles may or may not participate in swallowing. When they participate, they may do so in a graded manner, and, in contrast to the obligate muscles, are very sensitive to feedback. Examples of such muscles are the extrinsic tongue muscles, facial muscles (especially the lips), and the levator muscles of the mandible (Fig. 60).

The degree to which the facultative muscles participate is dependent on the demands for stabilisation of the tongue base and the adequacy of structures in the front of the mouth to effect an anterior oral seal. When swallowing liquids or saliva, the tongue requires less stabilisation than when swallowing resistant boluses; there may be little or no contraction of facial and mandibular levator muscles. For increased stability of the tongue base when swallowing a solid bolus, the mandible may require stabilisation as well. If the subject is dentate and has an acceptable occlusion, the teeth will be brought together. If the subject is without teeth (e.g., infant) or has occlusal discrepancies (e.g., severe occlusal interferences, skeletal open bite), mandibular stabilisation may be effected by the facial muscles. If the maxillary incisors are in an extreme overjet relationship, the anterior seal may be effected in part by the lower lip. According to these authors (Dubner et al., 1978) where there is a localised anterior open bite, the tongue will seal off the open bite by the familiar response of "tongue thrusting".

The facultative muscles of swallowing undergo developmental changes, in contrast to the obligate muscles which are programmed from before birth. The facultative muscles, prior to the eruption of the primary teeth, are different from those participating after the acquisition of a full dentition. The infantile swallow is characterised by activity in the orbicularis oris and buccinator muscles, the active thrusting of the tongue, and an absence of activity in the levator muscles of the mandible. Following the eruption of the teeth in most individuals, the lips and buccinator become minimally active, whereas the levator muscles dominate, particularly in solid bolus swallows. The tongue then ceases to thrust as vigorously as in the infantile swallow, developing into the "adult" swallow. This will be further examined in a later section.

Whether a swallowing muscle then, is obligate or facultative, will have an important bearing on its capacity for adaptability. Dubner et al. (1978) then refer to tongue thrust swallowing. They point to the studies of Lowe (1976) and Lowe et al. (1977) whose studies have indicated that tongue thrusting results from contraction of the genioglossus muscle in cat, monkey, and man. They add that since it is possible to place fine, bipolar-wire electrodes in this muscle and record its activity in swallowing, it is possible to examine its role in swallowing synergy. They then postulate that if the tongue thrust is adaptive, it should be possible to alter the participation of the muscle in swallowing by altering feedback, e.g., correct an open bite. The genioglossus would then be classified as a facultative muscle. On the other hand if the tongue thrust is not adaptive, the participation of the genioglossus will be very rigid, i.e., the genioglossus is an obligate muscle. The genioglossus is thus unclear in its classification (Fig. 60) and may differ from patient to patient.

Clinically, <u>determining whether the genioglossus is obligate or facultative would be invaluable in planning treatment</u>. If it participates as a facultative muscle (i.e., tongue thrust is <u>adaptive</u>), correction of the factor(s) accounting for the adaptation (e.g., anterior open bite, large tongue, inflamed tonsils), should result in its return to normal. If it participates in swallowing as an obligate muscle, perhaps this will be indicative of an "endogenous" pattern of tongue posture, and the enormous difficulty for correction would be identified. The ability to determine its nature, however, is not yet available.

Doty (1968) emphasised an important principle established by electromyographic studies - that the pattern of muscular activity in swallowing can show great <u>variation</u> from one individual to another. There is no evidence on which to judge whether this arises from variations imposed by higher centres on the swallowing centre in the medulla oblongata, or whether the swallowing centre is itself variously organised in different individuals. For humans, probably both conditions prevail. In anaesthetised or decerebrate animals, some evidence suggests that the activity of the swallowing centre may show individual variations.

2.4.3 Initiation of Swallowing

How is swallowing initiated during mastication? Storey (1976) pointed out that if swallowing occurred when the bolus particles are degraded to a certain size a number of paradoxes were produced. First, the regions of the mouth best equipped to monitor particle size, e.g. the teeth, tongue, and palate, do not give rise to swallowing. Secondly, as the particles are degraded they would be less likely to excite these receptors. Thirdly, the oropharyngeal sites which do give rise to swallowing are covered by the tongue during mastication. These most reflexogenic sites are the faucial pillars and the posterior pharyngeal wall.

Storey then cites the finding that the most reflexogenic sites for swallowing are the epiglottis and larynx. He speculates therefore that it is the aqueous vehicle of the bolus and/or saliva dribbling down over the back of the tongue onto the epiglottis that triggers off the swallow, since the laryngeal swallow can be serving both an alimentary and a respiratory function. Therefore the rapidity of swallowing could be proportional to the fluidity of the bolus. He applied this then to practical experience and found that we swallow liquids at once and succulent foods very quickly. The swallowing threshold for other foods, then, might be a function of how rapidly they stimulated salivary flow as a result of gustatory or mechanical stimulation. Thus, swallowing elicited in the epiglottis and rostral larynx, and not the pharynx, serves both alimentary and respiratory functions.

Hiiemae, Thexton, and Crompton (1978) reviewed a neurophysiological model of Thexton (1976) (Fig. 61). This model attempted to explain the mechanism of mastication, and was one of the first to recognise the role of the tongue in feeding and to involve its movements in the explanation. The model was part of the hypothesis that food reflexly elicited those responses

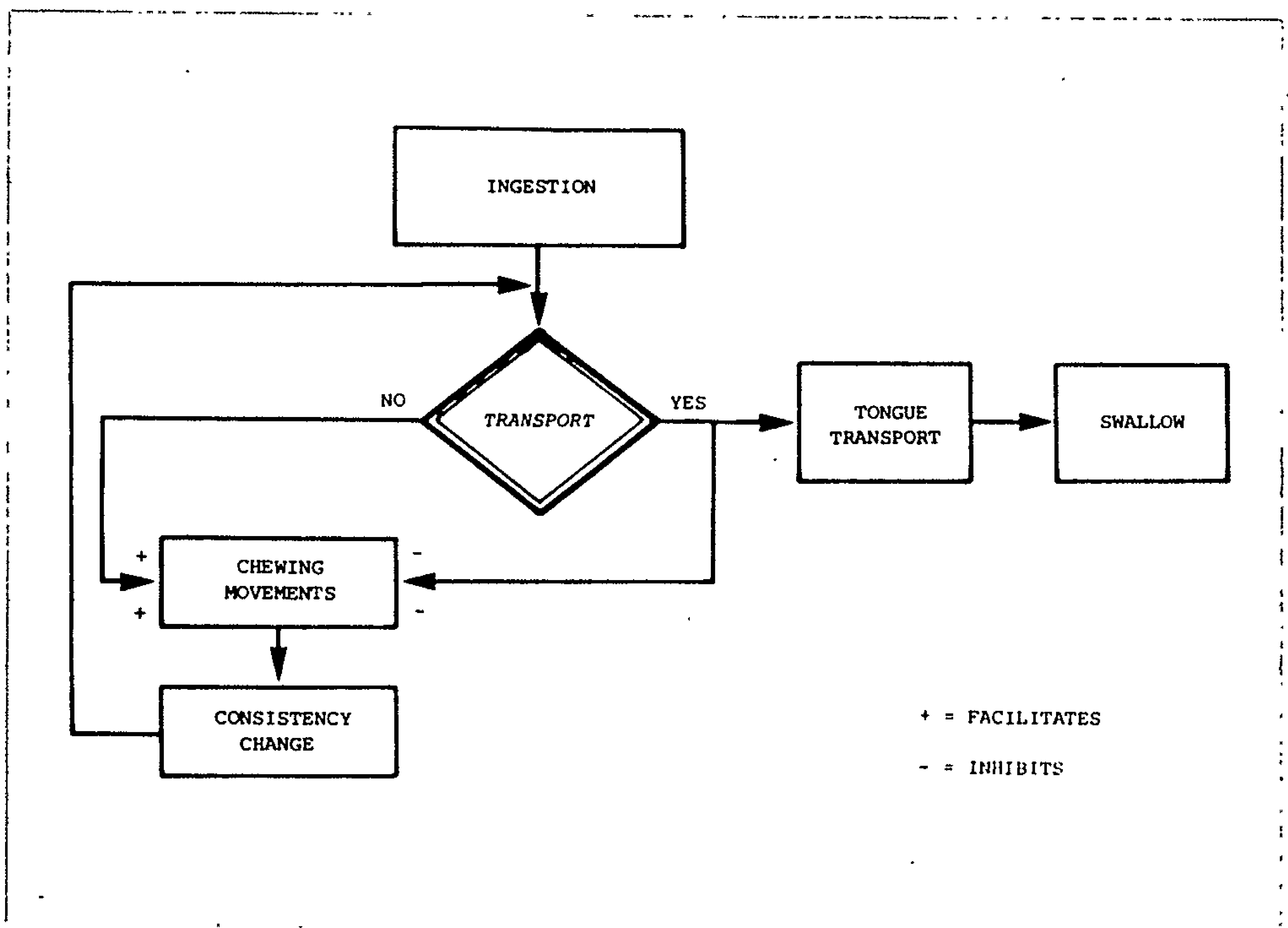


Fig. 61 Oral mechanisms in feeding (A). On entry into the mouth, food is divided by consistency into two categories: that which is suitable for immediate swallowing and that which is not suitable. The latter is then chewed until the consistency is changed so that it can be swallowed. (Hiiemae, Thexton, and Crompton, 1978)

most appropriate to its consistency. This hypothesis was based on Thexton's previous studies of jaw reflexes in the decerebrate cat (1973). Two general classes of oral reflexes were described. One group facilitated opening and closing movements of the jaws, while the other group inhibited jaw closure movements and produced a rhythmic ripple of activity on the tongue surface analogous to peristaltic activity. These reflexes were then seen as interacting with the rhythmic pattern of activity emanating from a central rhythm generator in the brainstem.

The model indicates that when ingested food first enters the mouth, its consistency is assessed to decide whether or not immediate transport to the fauces with consequent reflex swallowing is the appropriate course of action. The model assumes that liquids and soft foods are processed in this way and that masticatory movements are largely, if not completely, suppressed. On the other hand, food unsuitable for transport elicits increased jaw movement and so facilitates its own degradation. The physical state of the food is visualised as being under constant review so that transport towards the fauces can supervene at any time. These authors point out that the major implication of this model is that sensory feedback from oral mucosa is the major determinant of oral behaviour rather than feedback from periodontal, joint or muscle receptor systems. The other implications are:

1. that soft food and liquids are similarly treated;

2. that hard food is not subjected to intraoral transport until it has been chewed and physically degraded; and

3. that a reflex swallow always results once a bolus reaches the fauces.

These authors conclude that all food has to be reduced to a particular key consistency before swallowing, in order to trigger the intraoral transport system. A common terminal sequence can be expected, therefore, for all feeding behaviours irrespective of the initial consistency of the food.

Hiiemae, Thexton, and Crompton, in studies on mammals (cats in particular), and a pilot study on humans, found that the model as presented was not consistent with their findings. The model implied that all food was reduced to a particular acceptable consistency before being swallowed. However, they found that when an animal was feeding on a single type of food, bolus area appeared to be similar in each sequence. This suggested that swallowing might be triggered when the bolus had reached a threshold volume. They therefore found that the neurophysiological model (above) did not take into account or explain:

(1) why transport operates as a two stage process;

(2) why the transport of liquid through the oral cavity requires fewer cycles than does transport of soft food;

(3) how solid food displaced forward by the cheek teeth is accurately repositioned by a transport mechanism;

(4) why the swallow threshold is volume variable depending on bolus consistency; and

(5) how bolus accumulation and partial or suspended swallows can occur.

A new model of feeding was proposed (Fig. 62). It was a synthesis of what they saw as the basic behavioural elements in the feeding process. On entry into the mouth, and upon acceptance as a food item, the food is transferred to the molar region (stage one). Here the food is divided by consistency into two categories - that suitable for further transport and that not suitable. The food in the latter category is then chewed until its consistency is changed so that it too is suitable for further transport. Food is

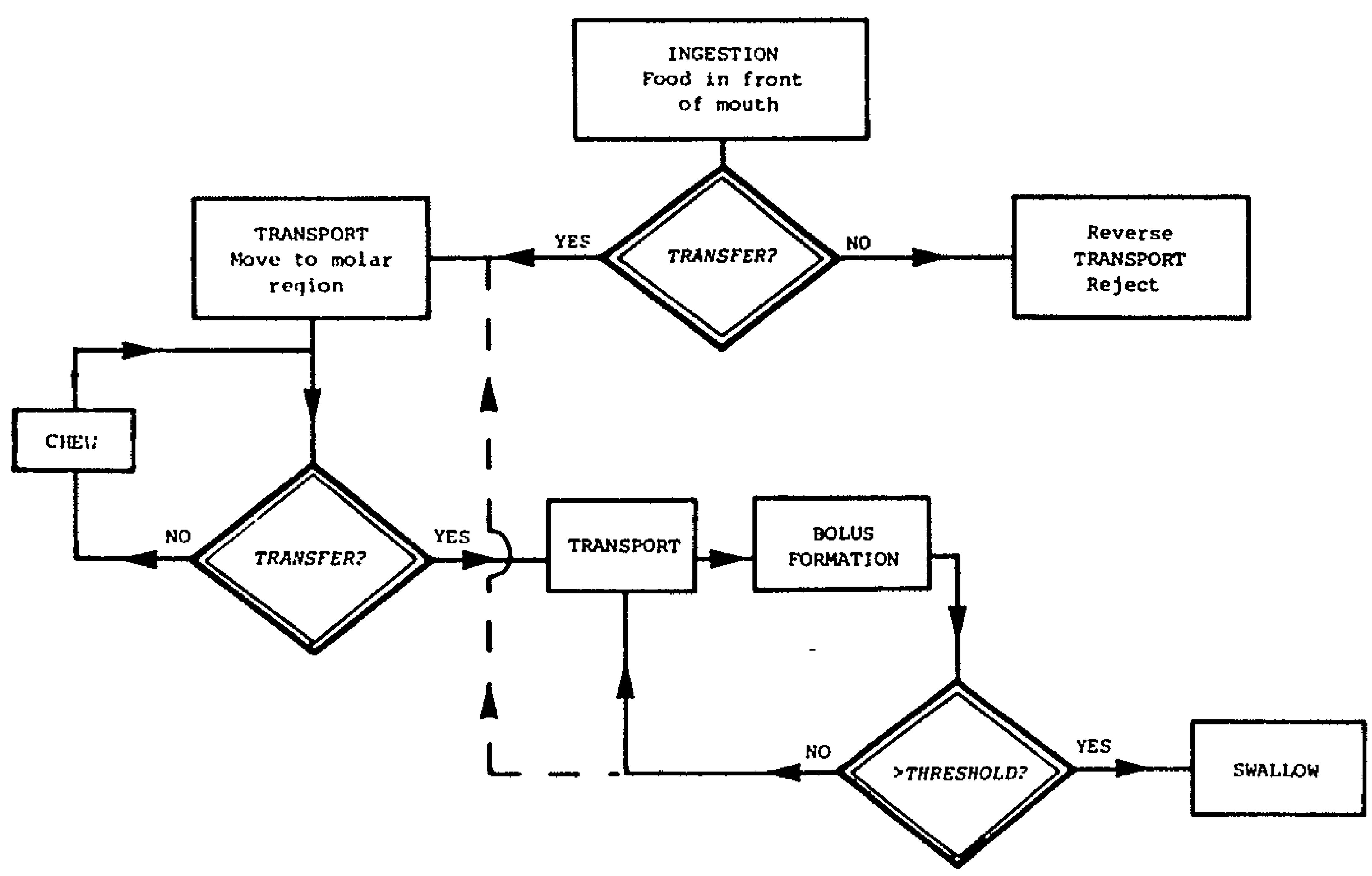


Fig. 62 Oral mechanisms in feeding (B) - a new model. On entry into the mouth and upon acceptance as a food item, the food is transferred to the molar region (stage one). Here the food is divided by consistency into two categories: that suitable for further transport and that not suitable. The food in the latter category is then chewed until its consistency is changed so that it too is suitable for transport. Food is then transported from the molar region to the back surface of the tongue (stage two). A bolus, therefore, gradually accumulates on the back surface of the tongue until the threshold (volume/time) for reflex swallowing is reached. (Hiiemae, Thexton, and Crompton, 1978)

then transported from the molar region to the back surface of the tongue (stage two). A bolus, therefore, gradually accumulates on the back of the tongue until the threshold (volume/time) for reflex swallowing is reached, i.e. has the accumulated mass sufficient volume to warrant activating the swallow mechanisms?, or has the bolus been present for a sufficient time? If either or both of these factors has not reached a threshold level, then the bolus will be retained until the factors change. In summary, the model shows that the fundamental mechanism of feeding is the backward transference of food and that chewing is a mechanism by which food can be rendered acceptable for further transference. However, the authors point out that there is an essential difference between the <u>bulk</u> transport of food through the oral cavity (stages one and two) and the <u>local</u> transport occurring during chewing when food is repositioned within the molar region. The evidence of these authors suggests that <u>bulk</u> transport is produced by a combination of tongue (surface) and hyoid (tongue base) movement, while <u>local</u> transport in chewing may primarily be a function of tongue surface movement, as well as cheek activity. How then is bulk transfer effected?

Hiiemae, Thexton, and Crompton postulated further that if the tongue is the agent of food transference, unless that function is solely attributable to the intrinsic musculature, the hyoid will move (because of its associated musculature) and its movements can be regarded as reflecting the movements of the tongue base. However, the hyoid is seen also as a link bone between the cranium and the mandible, and as such must be related to the movements of the jaws. They then attempted to reconcile the two concepts of the hyoid as a lingual bone and as a link bone during normal feeding behaviour. They studied movements of the hyoid bone in food transference and found that the transport phenomenon, i.e. the basic mechanism of feeding, is associated with hyoid and tongue base movements which may be extremely complex and to some extent independent of the movements of the tongue surface. Further work in this field was advocated.

This leads to a closer review of the neural mechanisms involved in swallowing behaviour.

2.5 Neural Organisation and Control of Swallowing

There has been a great amount written on the neural mechanisms that initiate and control deglutition. Previous sections have covered some of the neurology of swallowing (Purpose of Normal Swallowing, Initiation of Swallowing). The following information is taken primarily from the comprehensive works of Doty (1968); Hannam and Sessle (1976); Dubner, Sessle, and Storey (1978); and Roth and Calmes (1981). The aspects of neural organisation that are of particular interest to this discussion only will be reviewed.

2.5.1 Cerebral Cortex Considerations

Williams and Warwick (1980) describe the cortical structures in great depth. What is the significance of the cerebral cortex in this discussion? If the cortex is examined, areas can be identified that have been assigned to the manifestations of cerebral function. Two regions of the frontal lobe have been identified, the precentral and the prefrontal. The precentral area is the one of interest here. It must be noted that modern thinking does not divide this area into motor and sensory functions. It has been found that these functions are no longer separable, as there is much overlapping of these functions. Hence the description "sensorimotor" is used instead.

These two frontal regions are situated anterior to the precentral gyrus, and have been identified as Brodmann areas 4 and 6 (Fig. 63). This, however, is older terminology; currently the whole of the precentral area is designated the first or leading somatomotor area (MsI) (Fig. 64). It has been found that stimulation of separate loci in this central sulcus area has elicited contralateral movements in different parts of the body. These areas involved are intimately concerned in the mediation of voluntary movements. The order of loci are represented in Figs. (65,66). Much detail has accumulated concerning this bodily 'representation' or 'brain mapping'. It has been established that the

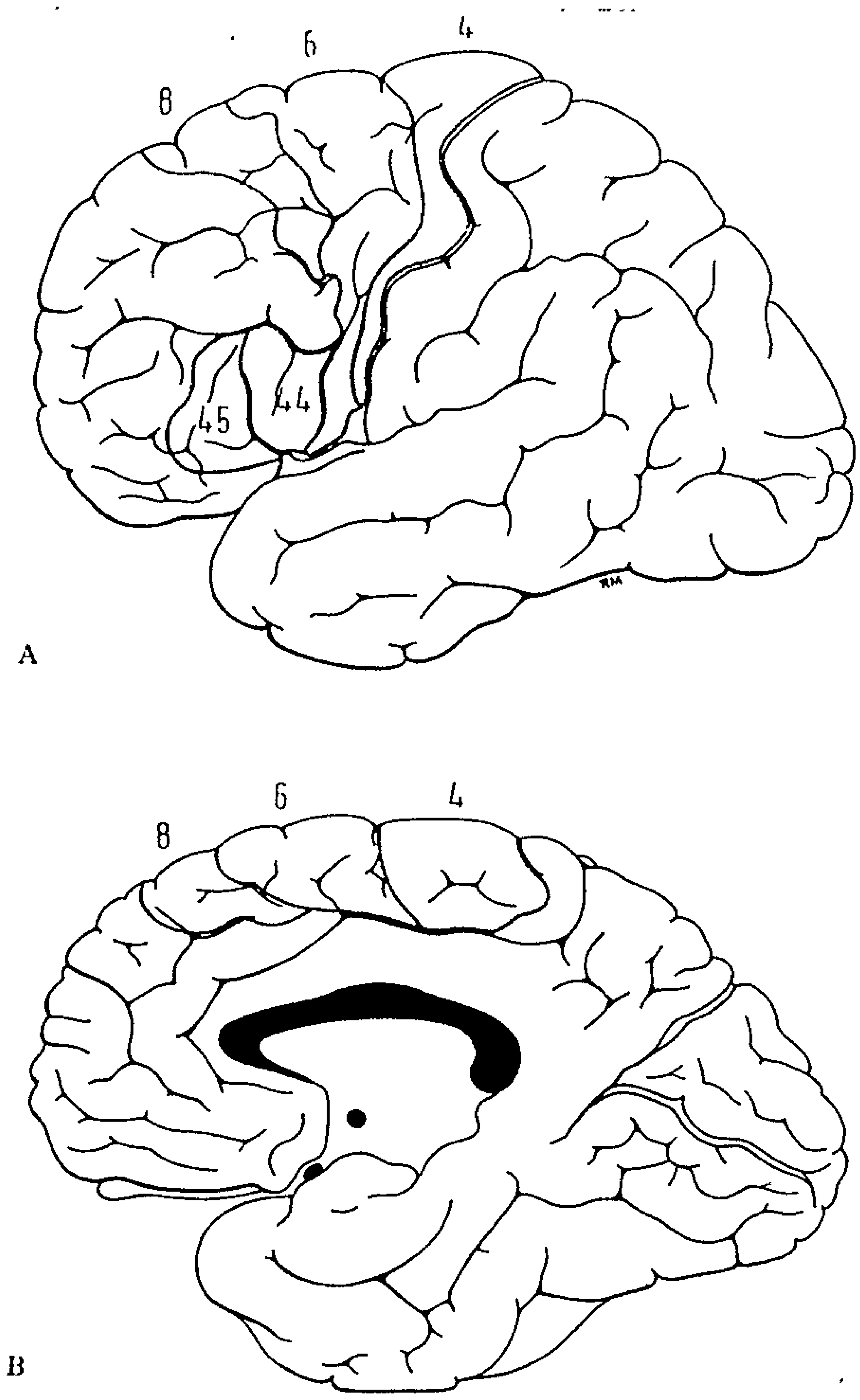


Fig. 63 Superolateral (A) and medial (B) surfaces of the cerebral hemispheres, showing approximate correspondence of the Brodmann areas to the main motor area (4) or MsI, the premotor area (6,8) and motor speech area of Broca (44,45). (Williams and Warwick, 1980)

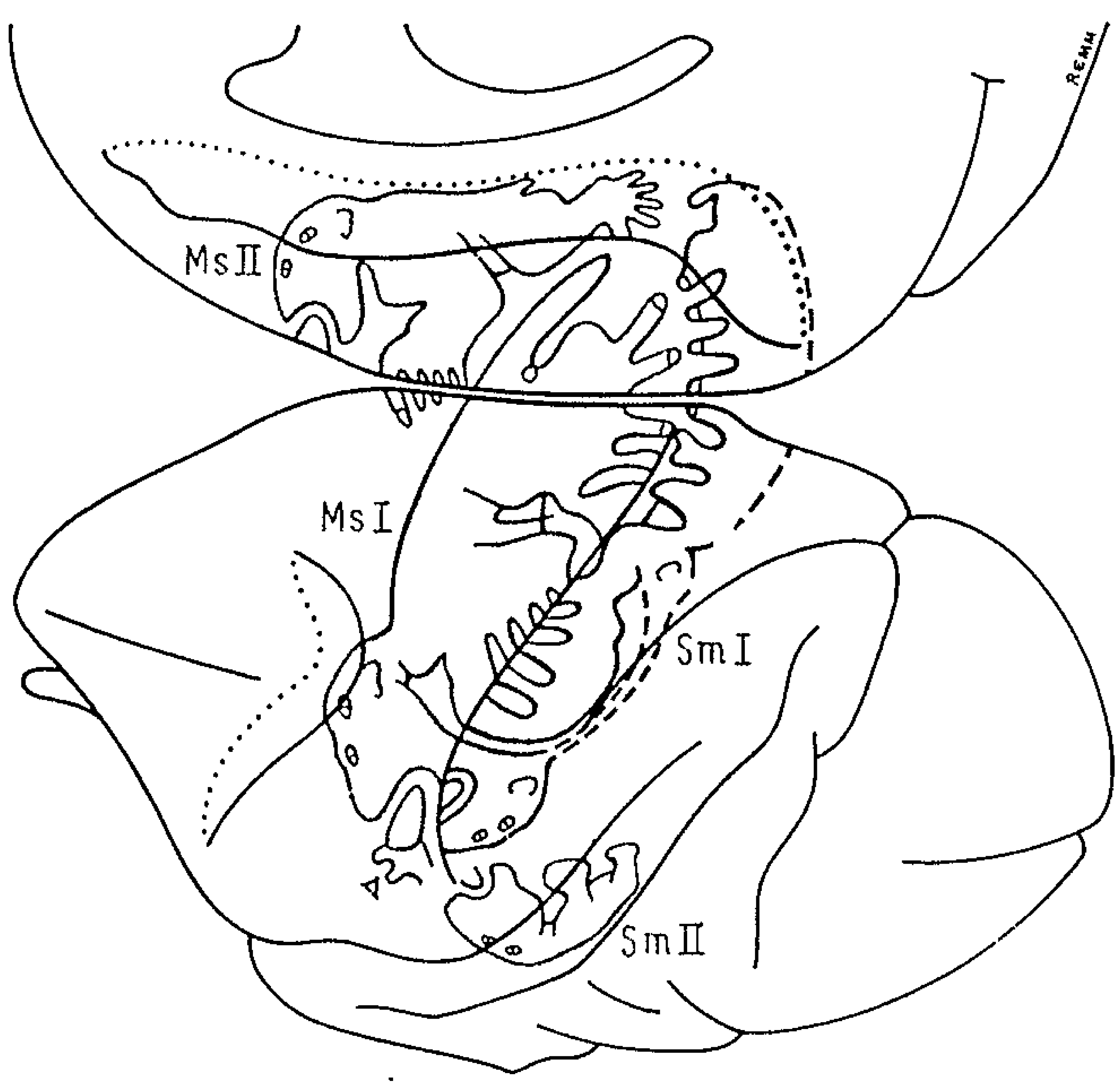


Fig. 64 The main sensorimotor areas projected diagrammatically upon the superolateral surface of the simian cerebral hemisphere. Note the somatopic arrangement in all four areas. (Williams and Warwick, 1980)

amount of cortex mediating movement in any particular region of the body is proportional not to the bulk of the muscle involved but to the skill with which it is customarily used. Figure (65) illustrates this phenomenon. Also of note is the sensory overlay noted in later studies (Fig. 66). From this it becomes obvious that the orofacial region has enormous cortical representation and therefore significance. Timms (1965) noted this also, pointing out that the oral mucosa has a sensory innervation ratio as high, if not higher, than any other body surface, "this is reflected in a large area of sensory cerebral cortex being devoted to this region with a corresponding area of the motor cortex".

Dellow (1976) observed that although a close physical oropharyngeal association of many of the physiological controllers of ingestion would appear to be phylogenetic, the representative liaison with the brain is "large and obvious". "This can be found in the innervation density, several vegetative centres, the large somatotopy within sensorimotor areas, related special senses, speech control, elements of the psyche, and in the multiple limbic zones related to consummatory behaviour. The central nervous relation also allows an integration of orofacial and oropharyngeal function with the functions of other parts and organs, and with behaviours other than the consummatory."

Also of note is the representation, specifically, of the tongue and associated structures. In fact, at the ventral tip of the region MsI is a segment reserved entirely for swallowing. According to Barrett and Hanson (1978) therefore, a center exists in the cerebral cortex for voluntary, conscious control of deglutition. They point out that a reflex consists of activity initiated at a subcortical level, and that if the total swallowing act is described as reflexive, then it is erroneous.

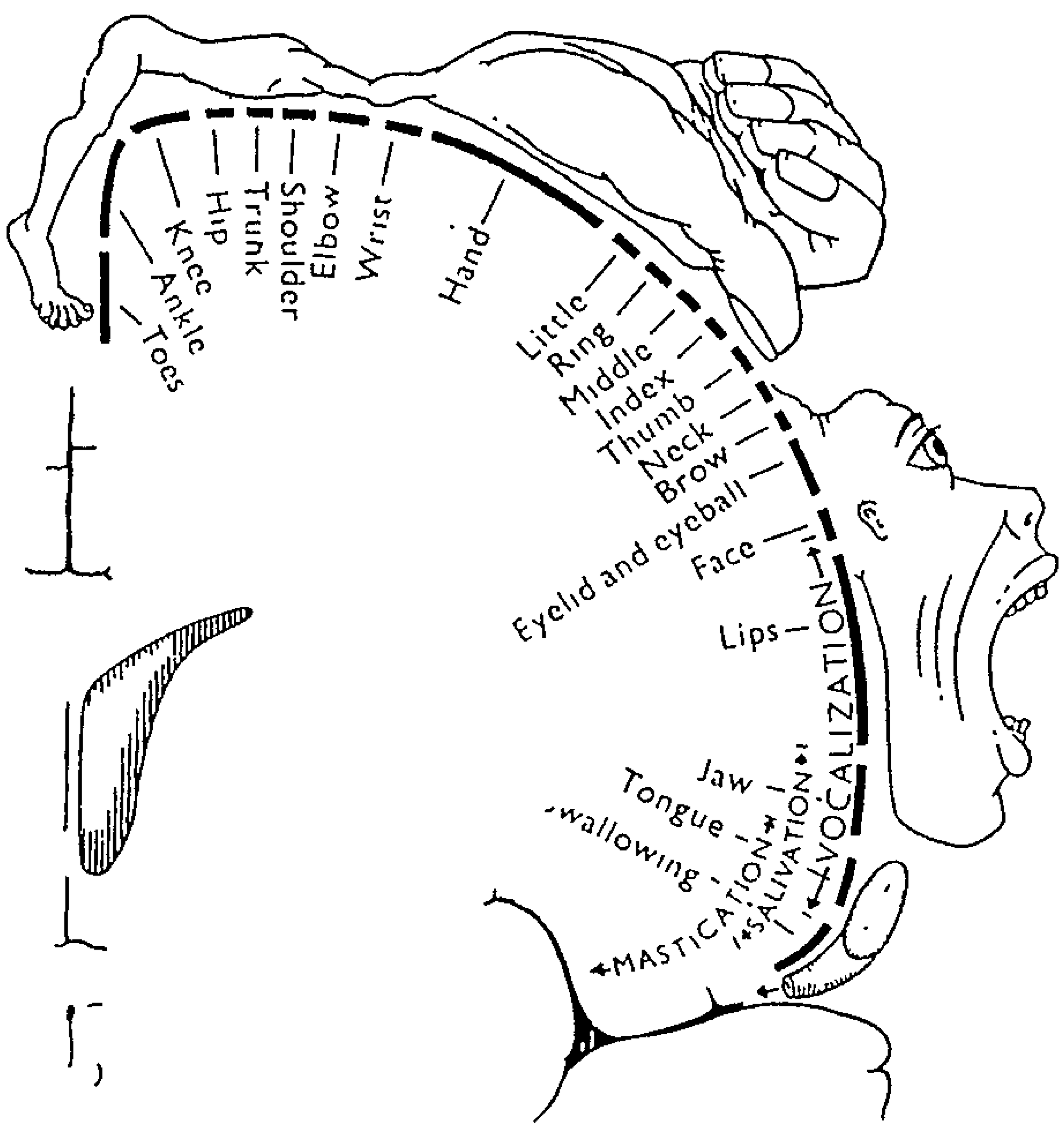


Fig. 65 The motor homunculus showing proportional somatotopical representation in the main motor area. (Penfield and Rasmussen, 1950)

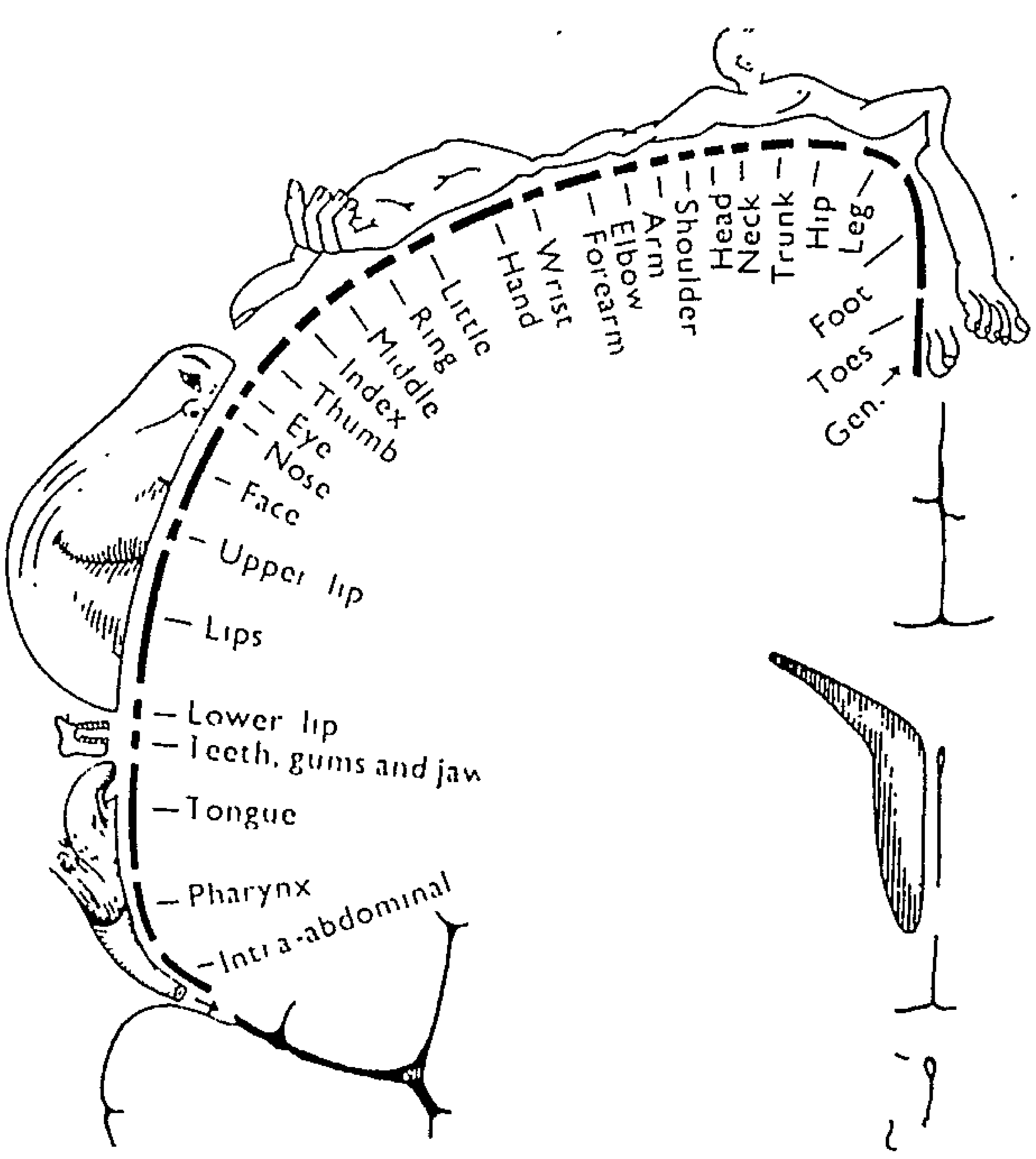


Fig. 66 The sensory homunculus showing proportional somatotopical representation in the somesthetic cortex. (Penfield and Rasmussen, 1950)

2.5.2 The Brain Stem

Of particular interest here is the medulla oblongata, or the inferior area of the brain. It serves as an organ of conduction for the passage of impulses between the brain and the spinal cord. It also houses the nuclei from which radiate four cranial nerves (IX, X, XI, XII), two of which (IX, XII) innervate the muscles of the tongue and palate. Vasoconstrictor and respiratory centres are found here as well as centres for defecation, salivation, coughing, sneezing, sucking, vomiting, and more importantly swallowing. These activities which, "to all intents and purposes, are visceral but which are undertaken by striped musculature apparently deserve special brain stem controls" (Dellow, 1976). Reticular neuronal assemblies are therefore found here.

Thus, the brain stem as a whole is concerned with vital processes and visceral and somatic functions. These can be modified by impulses entering from the cerebellum and the cerebral cortex (Barrett and Hanson, 1978). By the innumerable interconnections here, each area exerts some authority in its specialised field over every other centre and over the functioning of the total system. Thus, the integrity of the body as a whole is maintained, allowing many routine functions to be carried out quite efficiently at a subcortical level, including deglutition.

2.5.2.1 Brain Damage

The impact of neural deficit such as brain damage from either traumatic or congenital causes becomes more evident. Damage to specific regions of cortical tissue can have direct effects on body areas specifically related, and damage to brain stem tissue can have more profound disturbances to regulatory systems.

Storey (1976b) in a discussion paper reported on the possibility of modifications to swallowing activity, and the role of the tongue in those with cerebral palsy or poliomyelitis. It was revealed that swallowing was usually normal in lateral-facial dysplasia, but abnormal swallowing could be seen in those following cerebro-vascular accidents. Tongue function appeared to be affected when there was damage to hypoglossal nerve motoneurones or the cerebellum as a result of cerebral anoxia or kernicturus at birth or trauma later in life.

Some aspects of neural integration have been reviewed previously together with the description of the normal swallowing act. According to Doty (1968), to produce the "buccopharyngeal" component of this act the nervous system organises an intricate, reproducible, and bilaterally symmetrical sequence of excitation and inhibition, lasting over 500msec and involving at least two dozen motoneural pools on each side scattered throughout 1-2cm of the brain stem (Fig. 67). This is followed by oesophageal and gastro-oesophageal components lasting several seconds. Doty also (p.1889) examined and discussed the swallow centre in great detail in his mammoth study.

In summarising his study, Doty concluded that there are three distinct components of neural control systems: (1) the buccopharyngeal, (2) the oesophageal, and (3) the gastro-oesophageal, which usually interrelate in such a way as to produce the normal sequence of events in deglutition; but each can function as a separate entity. This seems to parallel the findings regarding the three stages of swallowing as previously described. He also found that the intricate spatiotemporal relations of the neural and mechanical events controlled by these systems proceed in a preordained manner and can run their full course without the benefit of afferent support. Furthermore, the

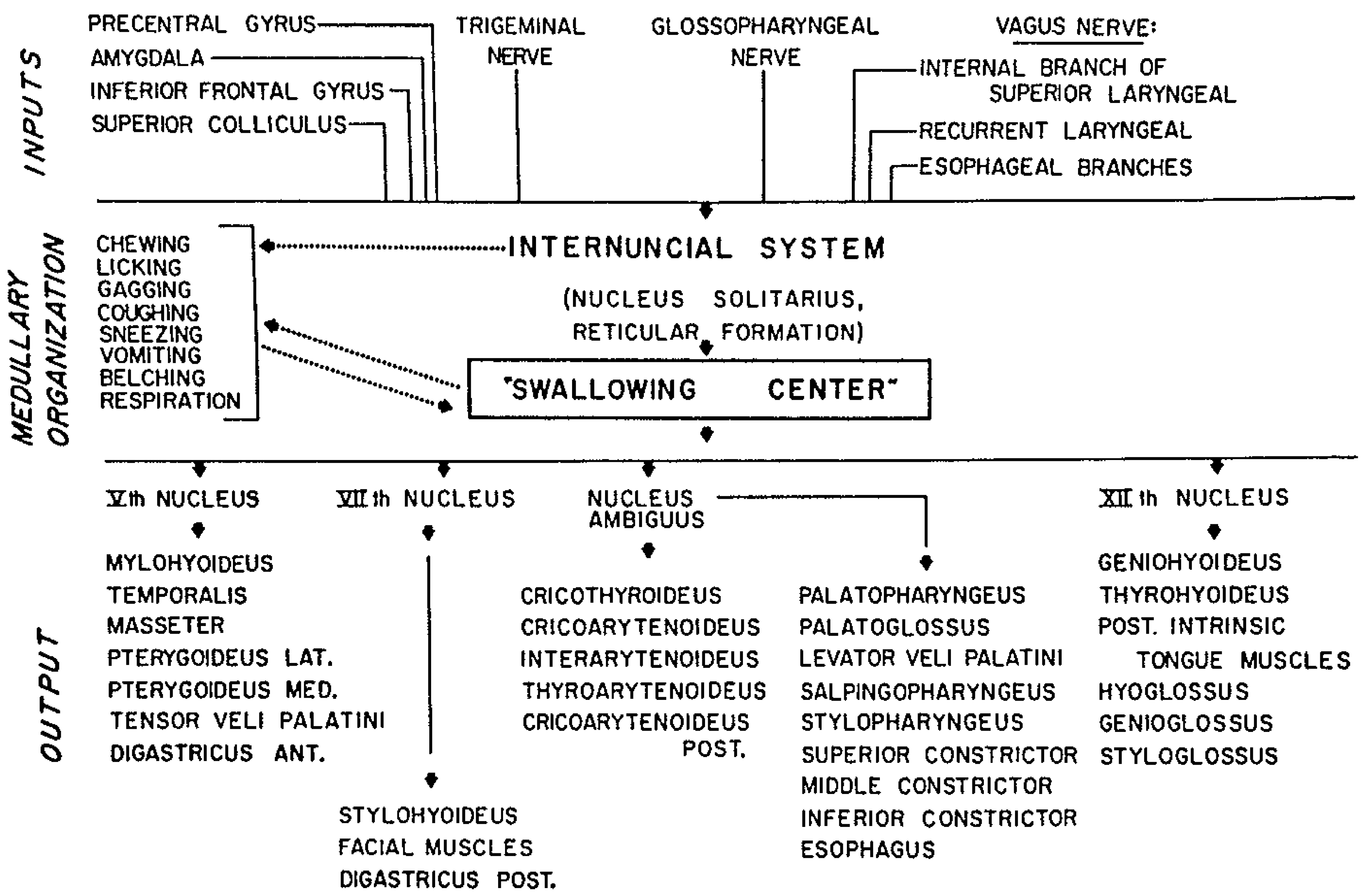


Fig. 67 Outline of afferent and efferent systems involved in swallowing, and the requirement of interaction between swallowing and other synergies. (Doty, 1968)

buccopharyngeal phase is almost impervious to modification by afferent action. The course of the oesophageal phase, however, is readily changed by afferent feedback from the oesophagus.

Doty also concluded that it is possible that swallowing can be initiated only by action of peripheral afferents; that is, that it cannot be elicited by excitation wholly limited to central systems more than a synapse or two beyond the input from peripheral sensory fibres, meaning that it is always reflexly rather than voluntarily elicited. The potentially effective afferent system is widely distributed through pharynx, epiglottis, larynx, and oesophagus, and probably arises from free nerve endings near the surface of the mucosa. Since a variety of reflexes can be elicited by similar stimuli in this area, the afferent portal of the swallowing centre is organised to accept only those stimulus patterns having a certain spatiotemporal code.

Apart from the other conclusions Doty also located the "swallowing centre". He wrote that the organisation of the buccopharyngeal component takes place wholly within this centre, which is in the medullary reticular formation. He described it as really being two half-centres which correlate their activity through extensive cross connections.

2.5.3 Reflex Activity

Davenport (1977) described the swallowing reflex briefly. He recorded swallowing as probably always a reflex act. Voluntary efforts to initiate swallowing, he wrote, are ineffective unless there is something, if only a few millilitres, to swallow. The reflex is started by stimulation of a large number of receptors in the mouth and pharynx, although he does not locate them. Afferent impulses travel in the glossopharyngeal nerve and the superior laryngeal branch of the vagus. These impulses go to the swallowing centre, and evoke the complex act of swallowing, in which there is discharge through six nuclei and motor neurons (Fig. 67). Afferent impulses mediated by the superior laryngeal nerve travel through relay stations in the pons and thalamus to the frontal cortex, and the swallowing reflex can be facilitated through efferent pathways from the frontal cortex to the swallowing centre.

Discharges from the swallowing centre through efferent pathways (Fig. 67) form a pattern of sequential contraction of buccopharyngeal muscles lasting about 0.5sec. The muscles involved are thought to be poorly provided with proprioceptors, and they contain no gamma-efferent system. Their pattern of discharge is substantially unaffected by procainization or transection of the muscles, according to Davenport. Feedback from the muscles plays, therefore, no significant part in determining the sequence or strength of their contraction.

During the oesophageal phase of swallowing, messages, reaching the swallowing centre by way of the afferent nerves from the oesophagus quantitatively modify the peristaltic wave motion.

In combining the considerations of the cerebral cortex, brain stem, and reflex activity Dellow (1976) presented a "hierarchical arrangement" of the neural structures controlling movements in the "ingestive apparatus" (Fig. 68). At the simplest level are the brain stem reflexes (X). These are applied to the neuronal assemblies associated with the basic controls of respiration (R), rhythmical sucking and mastication (M), deglutition (D), and salivation (S). The brain stem has general motor control sites in the reticular formation, pontine nuclei, cerebellar nuclei, red nucleus, and substantia nigra, while beyond this core, large neuronal pools in the cerebral cortex, limbic system, basal ganglia, motor thalamus, and cerebellum are involved in motor and behavioural control. Sucking and swallowing movements "sufficient for subservient sustenance" can be adequately controlled through the interplay of brain stem mechanisms alone. Ordinarily, automatic ingestive movements are keyed by the sensory inputs from appropriate material in the mouth and oropharynx, although non-nutritive sucking activity is normal in the neonate. Sensory input channels influence all levels of motor control. There is some evidence that the reappearance of spontaneous rhythmical jaw movements in the aged is due to an imbalance of cholinergic and dopaminergic mechanisms in the caudate nucleus of the basal ganglia. In addition to such specific chemical paths in the brain, a release of hypothalamic neurohumors and substances released secondarily from the pituitary gland are relevant to the behavioural overlay of motor control. The neural outputs are to striated musculature except for those to salivary and mucous glands, blood vessels, and to the lower half of the oesophagus. The circumoral (O), faucial (F), and cricopharyngeal (C) muscles can be considered as sphincters of the digestive tract; and likewise the vocal cords can be a protective sphincter of the respiratory tree. The vocal cords act in concert with the oropharyngeal musculature during speech, and the motor control of this behaviour necessitates a large cortical involvement. The second major receptive organ of ingestion, the stomach (G), is naturally involved in control, particularly with pre-feeding inputs to the brain,

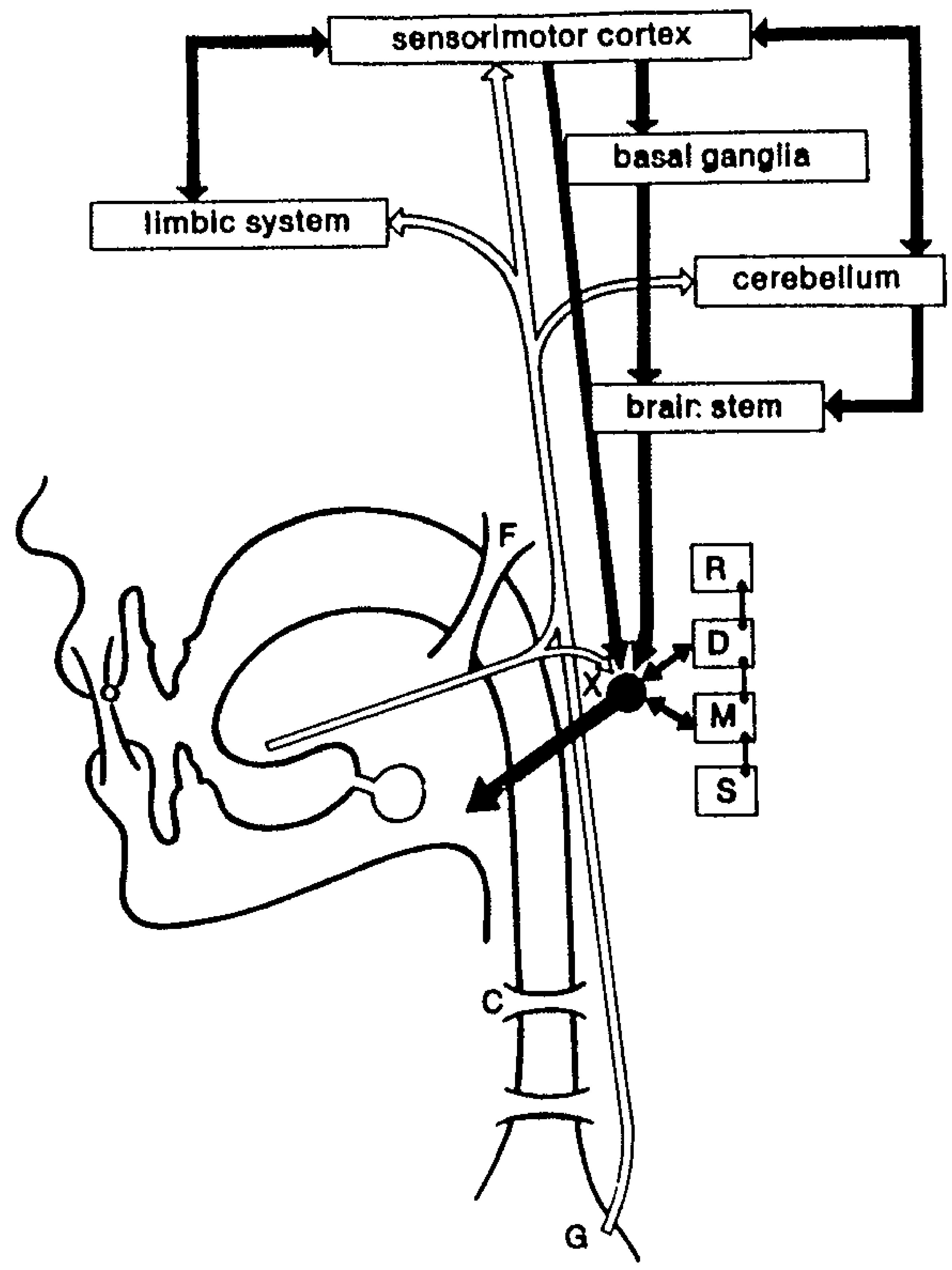


Fig. 68 Hierarchical arrangement of the neural structures controlling movements in the ingestive apparatus. (Dellow, in Sessle and Hannan, 1976)

MOTOR EVENTS IN SWALLOWING

SOLIDS			LIQUIDS
1. ORAL :	1.1	Moulding of bolus (V, VII, XII)	Present
	1.2	Retropulsion - anterior oral seal	
Mucosal receptors		Pressure gradient (VII)	
		- contraction of floor of mouth (V, XII)	
2. PHARYNGEAL :	2.1	Reflex inhibition of respiration	Present
(0.1 sec)	2.2	Closure of respiratory tract	
	2.3	Elevation of larynx	
Mucosal	2.4	Vocal folds (false +)	
receptors	2.5	Nasooharyngeal closure	
3. OESOPHAGEAL :	3.1	Relaxation of cricopharyngeus m.	Absent
	3.2	Oesophageal peristalsis	

Fig. 69 Table: Motor events in swallowing. (Klineberg, 1983)

post-ingestive inputs from distention, and conditioned responses. The tenth cranial nerve (Vagus) is its motor controller.

Klineberg (1983) described the swallowing reflexes in concert with their immediately preceding events of mastication. He noted the complexity of the neural mechanism in which a series of precisely programmed events take place in a very short time with interrelationships between sensory and motor components of cranial nerves V, VII, IX, and XII.

By combining the physiological aspects of swallowing with the neuro-physiological, a clearer picture was presented (Fig. 69).

1. Oral Phase:

(a) The food mass is moulded into a bolus. Moulding reflexes are mediated in the efferent path via the buccal branch of the Facial nerve to the buccinator muscle and the Hypoglossal nerve to the tongue musculature. Mucosal mechanoreceptors located in the mucous membrane of the cheek are activated by food contact. The afferent components of the reflexes are conveyed via the long buccal branch of the Trigeminal nerve to the spinal trigeminal nucleus. Klineberg continues with a description of the higher pathways.

Also of particular note is the coordination of reflex changes in tongue musculature with these cheek reflexes. The afferent limb of the reflex is conveyed via the sensory nerves to the tongue - the lingual branch of the Trigeminal nerve for the anterior two-thirds, and the Glossopharyngeal nerve for the posterior one-third. Afferent fibres pass to the Hypoglossal motor nucleus where the fusimotor (gamma efferent) neurones of intrinsic tongue muscles are stimulated. The efferent limb of the reflex is conveyed via the Hypoglossal nerve to the tongue [the genioglossus in particular (Miller, 1979), Fig. (72)] evoking spindle reflexes and resulting in coordinated changes in muscle tone.

(b) Retropulsion of the bolus into the pharynx. This is dependent upon development of an anterior oral seal for correct pressure equilibration. Anterior oral seal reflexes involve the buccal branch of the Facial nerve innervating the orbicularis oris, supported by the Hypoglossal innervation of the tongue musculature.

Klineberg makes particular reference to oral dysphagias. He suggests that structural deformities of the lip, such as a cleft, or any abnormality of the incisor teeth such as an anterior open bite or a skeletal Class II, Division 1 malocclusion with a pronounced overjet of the maxillary incisors, may interfere with the anterior oral seal and will result in abnormal lip and tongue reflexes. Tongue and lips are postured in such a way as to provide as effective an oral seal as possible. Pathology, also, of the floor of the mouth, may prevent the tongue being elevated adequately which may prevent the development of the intra-oral pressure gradient.

2. Pharyngeal Phase: In order to maintain the alimentary tract and protect the airway, a complex series of neuromuscular events occur reflexly and simultaneously over a 0.1sec period.

(a) Reflex inhibition of respiration occurs irrespective of the phase of respiration that is taking place.

(b) Closure of the respiratory tract. Reflex elevation of the soft palate is initiated by the stimulation of mechanoreceptors in the mucous membrane around the faucial orifice.

(c) Elevation of the larynx.

(d) Sphincteric action of the larynx.

(e) Nasopharyngeal closure. The innervation of the musculature involved has been described previously. With a palatal cleft, paresis of the soft palate, or nasopharyngeal carcinoma, this closure may not occur satisfactorily and liquid and food may pass into the nasal cavity. Apart from clefts, tumours are responsible for the majority of pharyngeal dysphagias.

3. Oesophageal Phase:

(a) Relaxation of cricopharyngeal muscle. Normally this is reflexly evoked by stimulation of the mucosal mechanoreceptors on the posterior pharyngeal wall as a result of contact by the food bolus.

(b) Establishment of laryngopharyngeal and oesophageal pressure gradients, and

(c) Oesophageal peristalsis.

Roth and Calmes (1981) describe swallowing as an innate, unlearned behaviour first manifested in foetal life, in contrast to mastication. They point out, as well, that in addition to its reflex initiation from the pharynx and larynx, swallowing can be induced voluntarily, but apparently food or liquid must be present for the volitional swallow to occur. This implies that central descending influences related to a command for swallowing require peripheral support.

They also describe swallowing as a triggered, all-or-none sequence of movements, that is, once it is initiated it goes to completion and, but for exceptional circumstances, the sequenced events cannot be interrupted.

2.5.3.1 Central Mechanisms and Sensory Regulation

According to Roth and Calmes (1981) although swallowing is reflexly triggered from the periphery, its timed sequence of muscle activities, and the movements they produce, is orchestrated by the brain. They also mention the swallow centre as the brain stem pattern generator for swallowing. In response to a peripheral stimulus or central command to swallow, the neural program of this centre exerts the sequential, all-or-none pattern of excitatory and inhibitory effects on the various motoneurons supplying the swallow muscles. The organisation of the swallow centre is still unclear, and they depict it as a "black box" (Fig. 70). However, neurons of the solitary tract nucleus appear to be intimately involved, at least in selecting the incoming sensory messages from the larynx or pharynx that are the appropriate trigger signals for swallowing. Also unclear is how the brain distinguishes between these patterns of sensory input as opposed to those giving rise to gagging and coughing that are also elicited from the larynx or pharynx.

The swallow centre also receives inputs from central descending pathways, and a number of cerebral cortical and subcortical sites can initiate or modify the swallow pattern through interaction with the peripheral inputs to the brain stem. Importantly, although not generally susceptible to central control, the patterned sequence of muscle activities can be modified to some degree with learning; for example, patients who have had their larynx removed because of cancer can partly swallow air, trap it in the oesophagus, and then express it slowly to form speech patterns (oesophageal speech). Other examples cited in the literature are the "sword swallower" and the "beer guzzler" (Doty, 1968; Davenport, 1977). By learning to forego much of the oral and pharyngeal phases of swallowing they are able to perform these feats.

The swallow centre can function without sensory feedback (Roth and Calmes, 1981). It only needs sensory information to trigger the sequence. Thus, in contrast to mastication, swallowing is not very sensitive to sensory

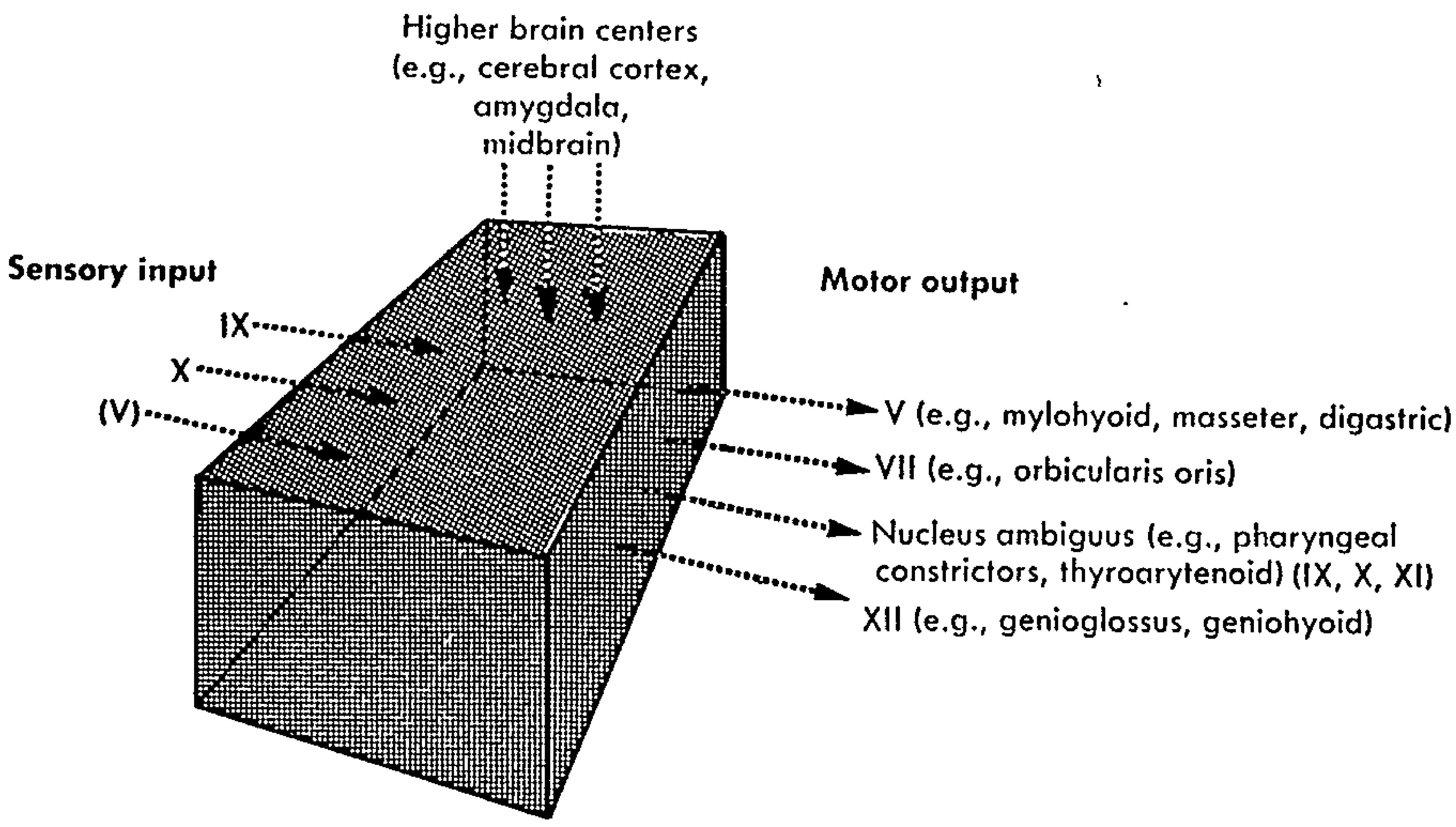


Fig. 70 Sensory and higher brain centre inputs and motor outputs related to swallowing. Swallowing can be reflexly initiated by sensory information passing into brain stem along glossopharyngeal (IX) and superior laryngeal branch of vagus (X) nerve; in some species, sites supplied by trigeminal nerve (V) may be involved. A number of higher brain centres also influence brain stem "swallow centre", represented as a black box. Outflow of swallow centre influences output of various cranial nerve motor nuclei containing motoneurons that supply muscles active in swallowing. Main motor nuclei are trigeminal (V), facial (VII), nucleus ambiguus (IX, X, XI), and hypoglossal (XII). (Roth and Calmes, 1981)

inputs, and once started will go to completion in most circumstances. A small amount of sensory modification may, however, be possible. For example, the patterning of facultative muscle activity appears dependent on the type and consistency of the bolus being swallowed, and silent periods can be produced in obligate as well as facultative muscle activities (e.g., to the larynx) that may be related to the production of other protective reflexes of the alimentary and respiratory tracts that take precedence over swallowing.

In summarising, these authors describe the orofacial region as manifesting a vast array of both simple and highly complex motor activities. These activities have both peripheral motor and sensory components. Reflex activity can be of a "simple" nature - the tongue reflex is one type, as well as jaw-closing, jaw-opening, jaw-unloading, and horizontal jaw reflexes; facial reflexes; and laryngeal, pharyngeal, and palatal reflexes. These are basically excitatory reflexes.

Reflex activity can be influenced by inhibition from higher brain centres. More complex motor activities are involved in this type, e.g., masticatory, and protective reflex synergies of coughing and gagging.

An even higher level of complexity of organisation is seen with the rhythmic, automated activities of mastication, suckling and swallowing.

Mastication, suckling, and swallowing are themselves components of even more complex behaviours. They are associated with feeding and drinking, which are particularly dependent on the function of higher centres of the brain (Dellow, 1976). Sensory feedback, however, is also utilised for the initiation, maintenance, and cessation of these ingestive behaviours. This is important when we come to look at biofeedback and neuromuscular facilitation. Many of these higher brain centres are also concerned with other complex functions involving the oral cavity, such as oral aggression, facial expression, and speech.

2.5.3.2 Simple Tongue Reflex Activity

This activity is also important, for in contrast to swallowing activity, postural activity is more clearly understood. Unfortunately, only a limited amount of investigation has been directed at the reflex mechanisms initiating and controlling lingual motility.

Roth and Calmes (1981) describe what is known of this activity (Fig. 71). The tongue muscles are supplied by the medial and lateral branches of cranial nerve XII (Hypoglossal), which originates from the motoneurons of the hypoglossal nucleus in the lower brain stem. In common with the other orofacial reflexes, the interneurons linking the sensory nerve fibres with the Hypoglossal motoneurons are located in the trigeminal spinal tract nucleus, in the solitary tract nucleus, and probably also in the adjacent reticular formation.

Despite the many individual tongue muscles, most studies of tongue reflex activity have looked at overall reflex activity by recording reflex responses in the Hypoglossal nerve. Only a small number of investigations have been directed at reflex responses in a specific tongue muscle (e.g., genio-glossus) or in the motoneurons supplying that muscle. According to Roth and Calmes it is clear that reflex excitation can be evoked by tactile or noxious stimuli applied to a host of orofacial sites, including tongue, pharyngeal, palatal, and laryngeal mucosa, teeth, temporomandibular joint, and possibly

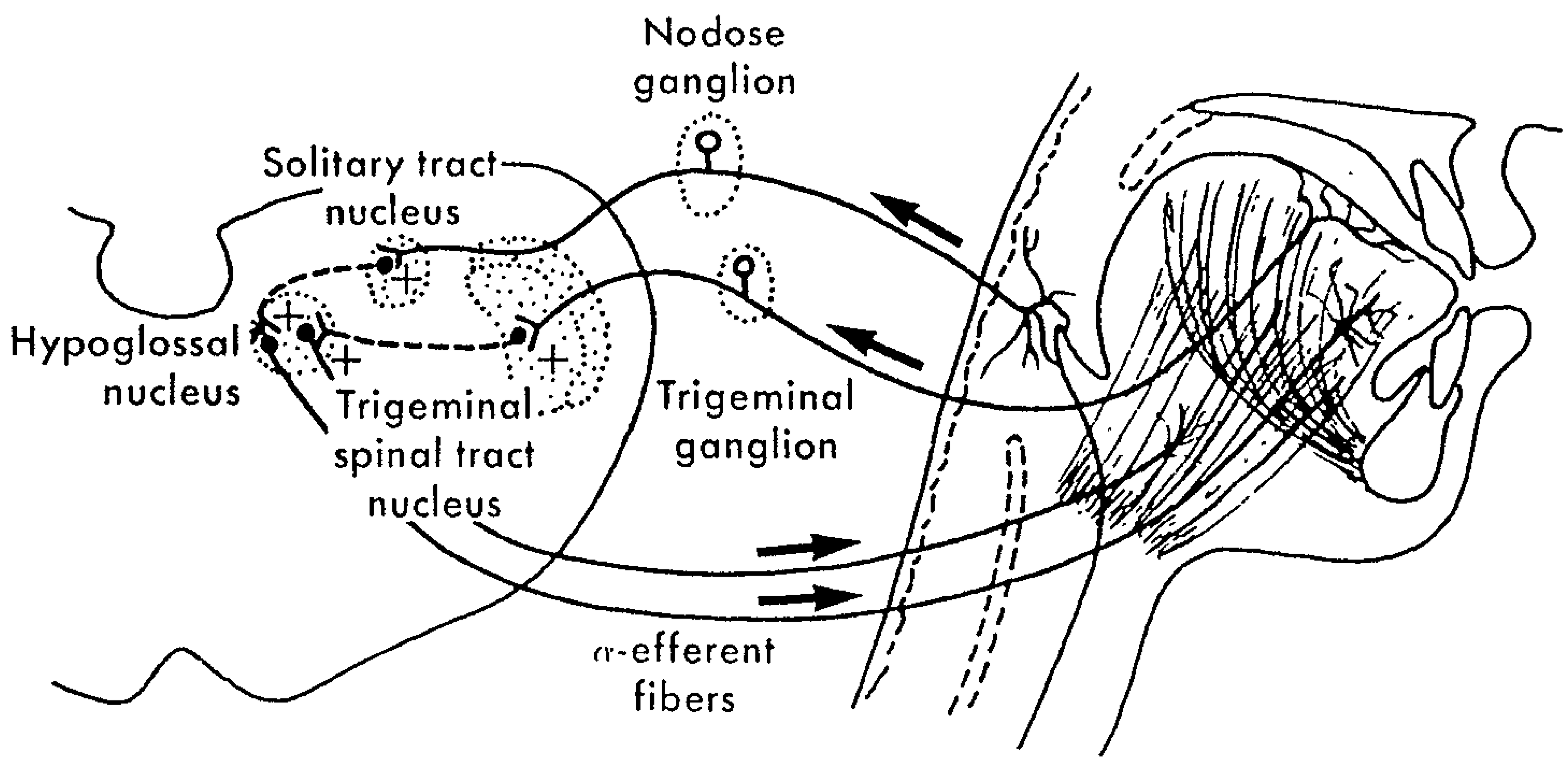


Fig. 71 Tongue reflexes evoked by stimulation of lingual or pharyngeal-laryngeal mucosa. Lingual mucosa afferent fibres pass through trigeminal ganglion to interneurons in trigeminal spinal tract nucleus; hypoglossal α-motoneurons supplying tongue muscles mainly involved in tongue retraction (e.g., hyoglossus) are then excited (+). Pharyngeal-laryngeal stimulus excites afferent fibres passing to solitary tract nucleus via nodose ganglion. From this nucleus, hypoglossal motoneurons are activated that mainly produce tongue protrusion (e.g., through genioglossus contraction).
(Roth and Calmes, 1981)

muscle afferent fibres. Recent studies in humans and experimental animals have suggested a pattern of organisation wherein stimuli in the anterior oral region or outside the mouth tend to have reflex effects favouring tongue retraction. In contrast, stimuli delivered to the temporomandibular joint or deeper intraoral sites (larynx and pharynx) primarily result in tongue protrusion (e.g., through reflex activation of the genioglossus muscle). The former reflex effects would help protect the tongue (e.g. during eating) whereas the latter would aid in the maintenance of a patent airway, such as in the event of a pharyngeal-laryngeal obstruction. According to Lowe and Johnston (1979) the protrusive reflex effects may also have clinical significance in certain malocclusions in light of findings that patients with an anterior open bite malocclusion have a much lower threshold for tongue protrusive activity in relation to jaw rotation than do subjects with a normal occlusion.

2.5.3.3 Other Clinical Implications

(A) Dubner, Sessle, and Storey (1978) have reported many investigations that have a direct clinical importance. Jaw activity has been found to be affected by reflex activity that has also affected tongue activity. It has long been thought that afferents from the jaw muscles themselves can influence tongue muscle activity. Since tongue reflex activity could occur with jaw opening and could be abolished by bilateral anaesthesia of the mandibular nerves at the foramen spinosum, stretch-sensitive receptors (e.g., muscle spindles) in the masseter muscle were implicated. It was also found that masseter nerve stimulation will elicit tongue reflex activity in the cat, but only those Hypoglossal efferents supplying the intrinsic or protrusive muscles.

Receptors in the medial pterygoid muscle have also been implicated. In addition, receptors in the temporomandibular joint, the afferents of which pass into the mandibular nerve, may provide an important modulation of tongue reflex activity. Temporomandibular joint receptors have been found to exert a definite and marked control of tongue activity, since the relationship between jaw opening and genioglossus muscle activity has been determined in human subjects (Lowe, 1977).

The importance of vertical dimension or face height has been implicated as a determining factor in tongue posture and motility. Joint receptors inform the brain of the degree of jaw opening and so their reflex effects on the tongue, particularly on the genioglossus and thus presumably the tongue's protrusive action, may be involved in certain malocclusions such as anterior open bite (Lowe, 1976) and in various orthodontic corrective procedures, e.g., monobloc treatment.

These authors cite the observations of Tulley (1969) in relating the tongue's contribution to the creation of an open bite to its postural activity. They also cite the work of Harvold (1968) on monkeys, where he found that an open bite could be induced by placing pieces of plastic in their palatal vaults. He speculated that crowding of the tongue resulted in jaw opening and forward posturing of the tongue, as the findings would predict. The jaw opening and tongue protrusion are conjoint responses to an infringement on the pharyngeal airway. Dubner et al. state that these reflexes protecting the pharyngeal airway can be initiated by natural causes such as enlarged or inflamed tonsils, large tongue, small maxillary or mandibular dental arches, or by the insertion of bulky appliances, e.g., monobloc or appliances restraining the tongue. The palatal crib, frequently used for the correction of tongue thrust swallow, exacerbates the problem of inadequate room for the tongue. The pharyngeal airway may be reduced in diameter as a result. Appliances that crowd the tongue may be contraindicated where interception further jeopardises the pharyngeal airway. This would further corroborate the observations of Thurow (1975). These aspects will be dealt with in detail in later chapters.

The tongue is normally maintained under postural control by the activity of the genioglossus muscle. However, this control may be lost in the unconscious state, e.g., under general anaesthesia. Two abnormalities of this postural control are seen in persons suffering from sleep apnea and Robin syndrome; in both cases the tongue's postural control is abnormal and impinges upon the pharyngeal airway (Dubner et al., 1978).

Temporomandibular joint receptors are just one of a number of orofacial receptors that can influence lingual motility. It would seem (Dubner et al.) that it is the <u>combined and integrated</u> action of all these <u>orofacial modifying influences</u>, in addition to <u>other factors</u> (such as respiration) that can modulate tongue activity, that underlies many of the successes and failures of clinical procedures that impinge upon tongue function.

Furthermore, Cleall (1965, 1972) found that by using palatal cribs, it was possible, by changing the sensory cues present within the mouth, to modify the resting posture and movements of the glossopharyngeal structures during swallowing. That these adaptive changes occurred, and occurred rapidly, and that they were reversible, would again seem to support the concept of a strong tactile sensory component in the neuromuscular control of deglutition. In summarising his findings, he found that neuromuscular coordinating mechanisms concerned with deglutition are highly developed and are sensitive to such influencing factors as <u>head position</u>, <u>oral contents</u>, <u>speech</u>, and <u>placement of oral appliances</u> (discussed at length in later sections).

Miller (1979) has graphically depicted most of the points of the foregoing discussion (Fig. 72), indicating the excitatory and inhibitory inputs affecting genioglossus muscle activity.

(B) Moyers (1973) has described the significant distinction between bodily reflexes: (1) Conditioned Reflexes, and (2) Unconditioned Reflexes.

(1) Conditioned reflex. This is an automatic response to a stimulus that previously did not elicit the response. The reflex is acquired by repeatedly pairing the 'neutral' stimulus with another stimulus that normally does produce the response, e.g., Pavlov's (1927) dog experiments. The basis for much behaviour, is the formation of conditioned reflexes.

(2) Unconditioned reflex. These are integrative processes that the central nervous system can accommodate due to the maturity of the system. The neonate at the time of birth expresses these unconditioned reflexes, such as blood pressure control, respiration, protective reflexes of coughing and sneezing, and the startle response. These are first tested at birth by applying the Apgar test and arriving at a score which will roughly determine the level of the infant's unconditioned responses. As the child grows, the nervous system continues to develop anatomically and to mature physiologically. Basic reflex patterns of muscle activity appear in a scheduled way. Even though the child may not have been taught any of these movements, these primary patterns of (i) unconditioned reflexes and (ii) reflexes that normally appear as a part of growth are the basis for the learning of those patterns of muscle activity that are called conditioned reflexes. It may be of note, as Proffit and Mason (1975) observe, that the rate of growth of the tongue closely approximates that of the growth of the neural tissues (Fig. 78), and may be a reflection of the complex interrelationship of lingual function and neural function.

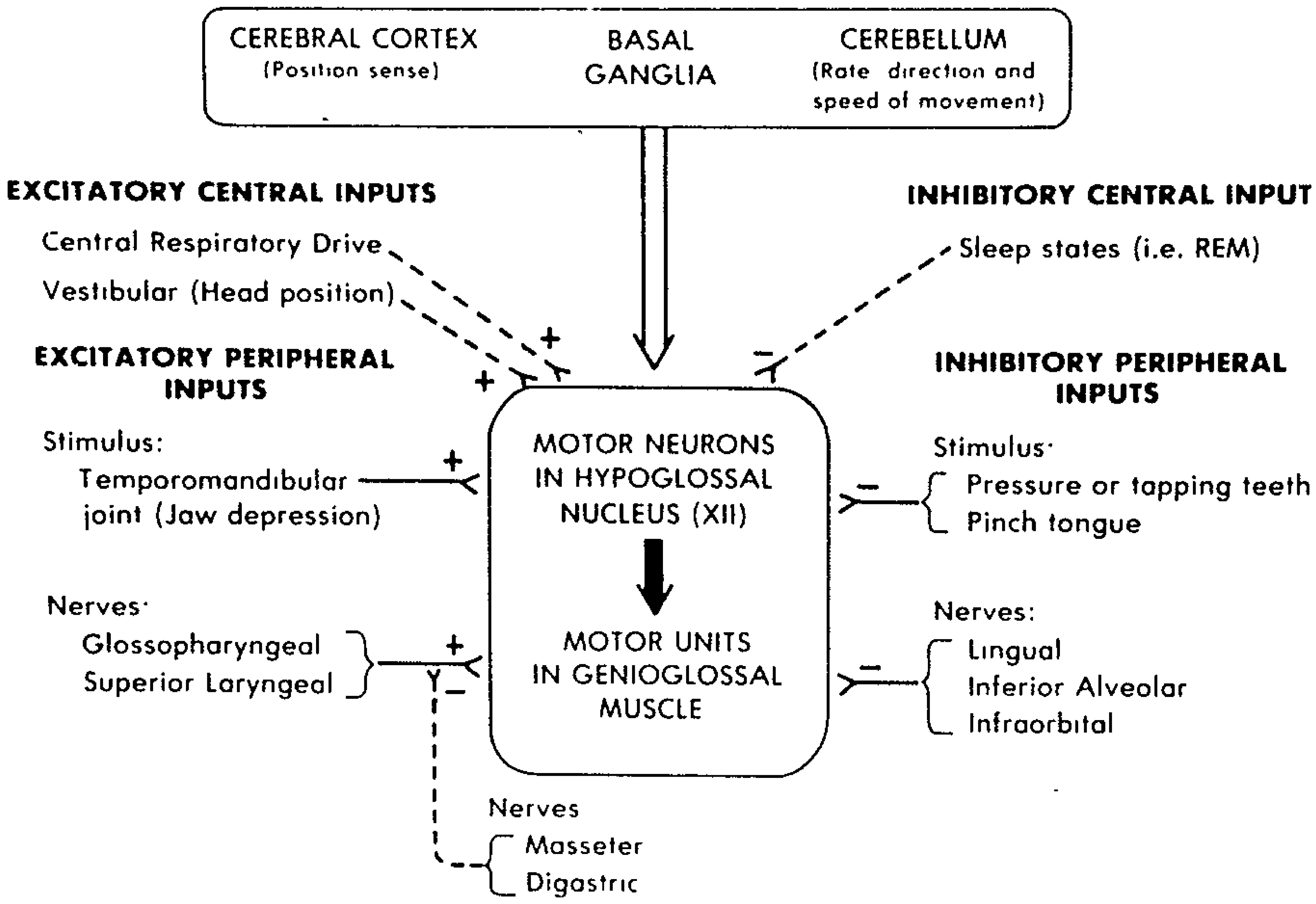


Fig. 72 Schematic diagram of the central and peripheral synaptic inputs that modify the discharge of motor neurons in the hypoglossal nucleus innervating the genioglossus muscle. Plus symbols indicate excitation of motor neurons and the negative symbol demonstrates an inhibitory influence. The genioglossus is active in tongue protrusion and exhibits both a rhythmic and tonic discharge which is dependent on the synaptic control of its motor neurons. (Miller, 1979)

Moyers (1973) in discussing muscle learning notes the division of behaviour in response to environmental stimuli into two aspects - endogenous and exogenous. Here we arrive at a most important aspect of swallowing behaviour. Can swallowing behaviour be controlled or modified through muscle learning? The primitive motor system of the neonate gradually comes under sensory control of basic functions that must operate before birth. These endogenous activities are the result of unconditioned reflexes during prenatal life concerned with primitive vital activities. According to Moyers, environment determines the level, timing, and coordination of many aspects of behaviour after the afferent system is intact and functional. However, endogenous behaviour persists, although it may be modified.

Little is known of how learning (conditioned reflexes, exogenous behaviour, etc.) is coordinated with the primitive phylogenetic demands of endogenous behaviour (unconditioned reflexes), but learning, training and evaluation have a marked effect on behaviour in higher mammals, especially humans. Moyers rebuffs those who claim it is not possible to alter "inherited" endogenous orofacial muscle behaviour. He points to the fact that:

(a) our knowledge of the genetic aspects of the jaw and facial muscles is very scant,

(b) muscle learning is superimposed on preformed patterns of endogenous behaviour,

(c) learning can modify, suppress, rearrange or facilitate much endogenous behaviour, and

(d) even some primitive endogenous activities can be modified, as in learning to swim and in speech training.

He also points out that muscle learning is thought to be largely a process of acquiring new conditioned reflexes. In this way, the various pathways through the brain are gradually developed and imprinted as the baby grows through infancy and childhood into adulthood. These pathways constitute "muscle memory". When a person decides to master a new motor skill the learning process involves three important stages. First, the brain must have a clear mental image of the task to be mastered. Second, new pathways must be established and the conditioned reflex reinforced by repeated practice of the new skill. Third, control of execution of the new skill must pass from the higher centres of the brain to the midbrain, brain stem and spinal cord.

The first stage involves conscious understanding during slow, meticulous practice of the new motor skill. The second stage involves much concentration as well during repeated practice to reinforce the new pathways. If the third stage is to be reached, cortical reinforcement must be minimised as the new motor skill becomes automatic and more reflexly controlled during execution. This process is seen in action by observing students of musical instruments, sports participants, those learning to drive a motor vehicle, students of dance, and, as Moyers indicates, in oral myofunctional therapy when a patient is learning a new swallowing pattern.

Moyers then classifies neuromuscular activities into:

(1) Unconditioned reflexes. As previously discussed, these do not involve conditioning or learning. Examples of these in the oropharyngeal region of the neonate are those of respiration, mandibular posture, tongue posture, infantile swallow, suckling, gagging, vomiting, coughing, and sneezing. They require minimal reinforcement and are very difficult to alter by usual conditioning procedures.

(2) Reflexes appearing with normal growth and development. No conditioned reflex is capable of being learned until all of the necessary units in the central nervous system and musculature have matured sufficiently to make possible that learning; hence Piaget's (1962) "ages and stages". What is not known is whether these reflexes would have been learnt naturally without outside input, or is there a certain amount of learning as a result of being taught. In the orofacial region, the mature swallow and mastication are examples of reflexes that normally appear with growth and development.

(3) Conditioned reflexes. These reflexes include all reflexes that have been learned, including unwanted habitual behaviour. Here Moyers classes tongue-thrusting and thumb-sucking as examples.

(4) Voluntary efforts. Here, wilful acts are under cortical control rather than the lower centres, where reflex activities are integrated.

(C) Storey (1976b) in his discussion on the mechanisms that contribute to the coordination of tongue movements during mastication and swallowing, reported that not much study had been done of higher centre effects, although several workers had shown Hypoglossal nerve activity locked to mastication and swallowing. Furthermore, there were apparently no studies of the results of stimulating the subcortical regions, cerebellum, etc.

2.5.3.4 Genioglossus Activity

As mentioned previously, the genioglossus muscle is the main muscle concerned with forward posture and protrusion of the tongue; and that it was not clear whether this muscle was an obligate or facultative muscle in swallowing. Storey (1976b) discussed the quasi-obligate pattern in swallowing, saying that it depended on whether or not the muscle was participating in an elective fashion before a certain time, and thereafter as an obligate muscle of the swallow. Again, the studies of Lowe (1973) were mentioned in which he reported that in the cat and monkey there are two types of genioglossus activity - activity that might precede the tightly programmed swallow, and activity that was part of it. They seemed to be two different things. Although the situation in Man is not known, it could account for success in myofunctional therapy in some cases, and failure in others.

2.5.3.5 Tongue Thrust Activity

Storey also reported on the discussion regarding the cause of tongue-thrusting. Some thought that an attempt should be made to find out from what part of the central nervous system the signals come that activate the genioglossal neurones responsible for the protraction. Do they come from receptors in and around the mouth, from the swallowing centre itself, or from higher centres? It was agreed that it would be necessary to better document human tongue activity, concentrating on specific muscles. The usefulness of cineradiographic techniques had previously been discussed and its significant limitations had been shown (Storey, 1976b; see also Hanson, Hilton, Barnard, and Case, 1970). Storey then reported that it was felt that direct vision of the tongue without disrupting its activity would be valuable. The possibility of fibre optics was raised, by a nasal approach. Ideally, a non-invasive three-dimensional monitor is required to observe tongue activity. Yoshida, Takada, Adachi, and Sakuda (1982) have made claim to the closest method of recording tongue activity to date using miniature surface electrodes with electro-myography. It was also noted that studies on tactile input and changes in vertical dimension would be helpful for this clinical problem.

2.5.3.6 Sensory Feedback

Sensory feedback is available from the Trigeminal nerve, Glosso-pharyngeal nerve, and superior laryngeal nerve afferents, etc. Storey (1976b) contrasted the roles of feedback in swallowing compared to mastication. Mastication has a central component upon which is imposed sensory feedback. People normally do not bite their tongues while chewing but do so if the lingual nerves are anaesthetised. In contrast, central programming would appear to dominate for tongue coordination during swallowing with little importance attached to sensory feedback.

Clearly, there appears to be much information regarding the neural aspects of swallowing and tongue posture. However, there are glaring deficiencies in understanding of the methods by which the lingual muscles, and the genioglossus muscle in particular, participate in swallowing activity.