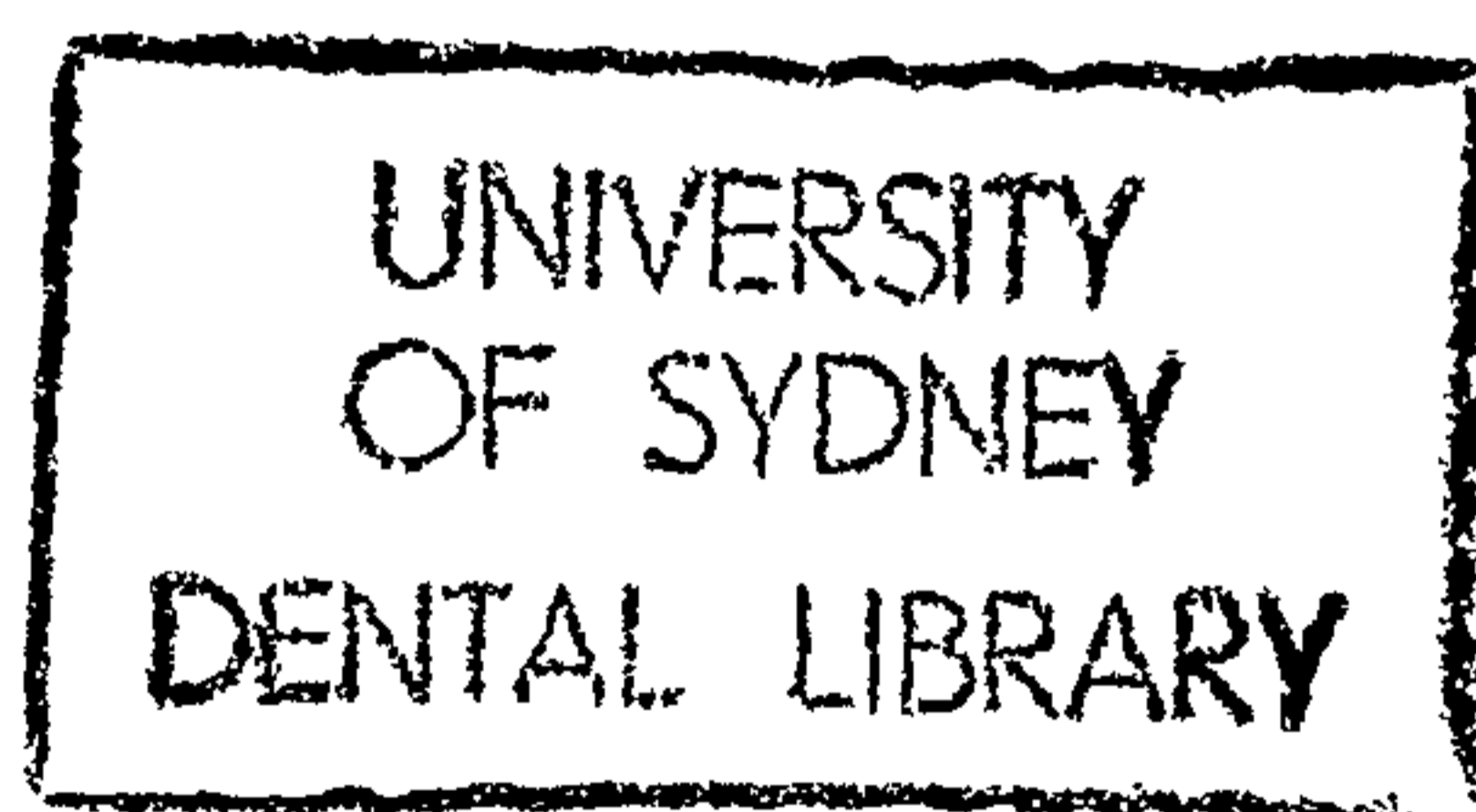


NASOPHARYNGEAL CONDITIONS AND DENTOFACIAL MORPHOLOGY

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PROLOGUE

The design of this thesis is based on the scientific philosophy originally propounded by Sir Karl Popper, and later adopted by Associate Professor Keith Godfrey, Department of Preventive Dentistry, University of Sydney.

The present research therefore began with problems and conjectured solutions for testing. From the research hypotheses, consequences were deduced amounting to anticipated observations. The resultant material and methods gave findings whereby the validity of the present hypotheses or innovations held by previous researchers were questioned, either wholly or in part.

It is felt that tables, graphs, drawings, and photographs often clarify and explain facts more than words could express, and are extensively used in this thesis.

It is hoped that evidence so presented raises more questions than it has solved, so that the science of Orthodontics may progress through relentless efforts by future researchers to answer these queries.

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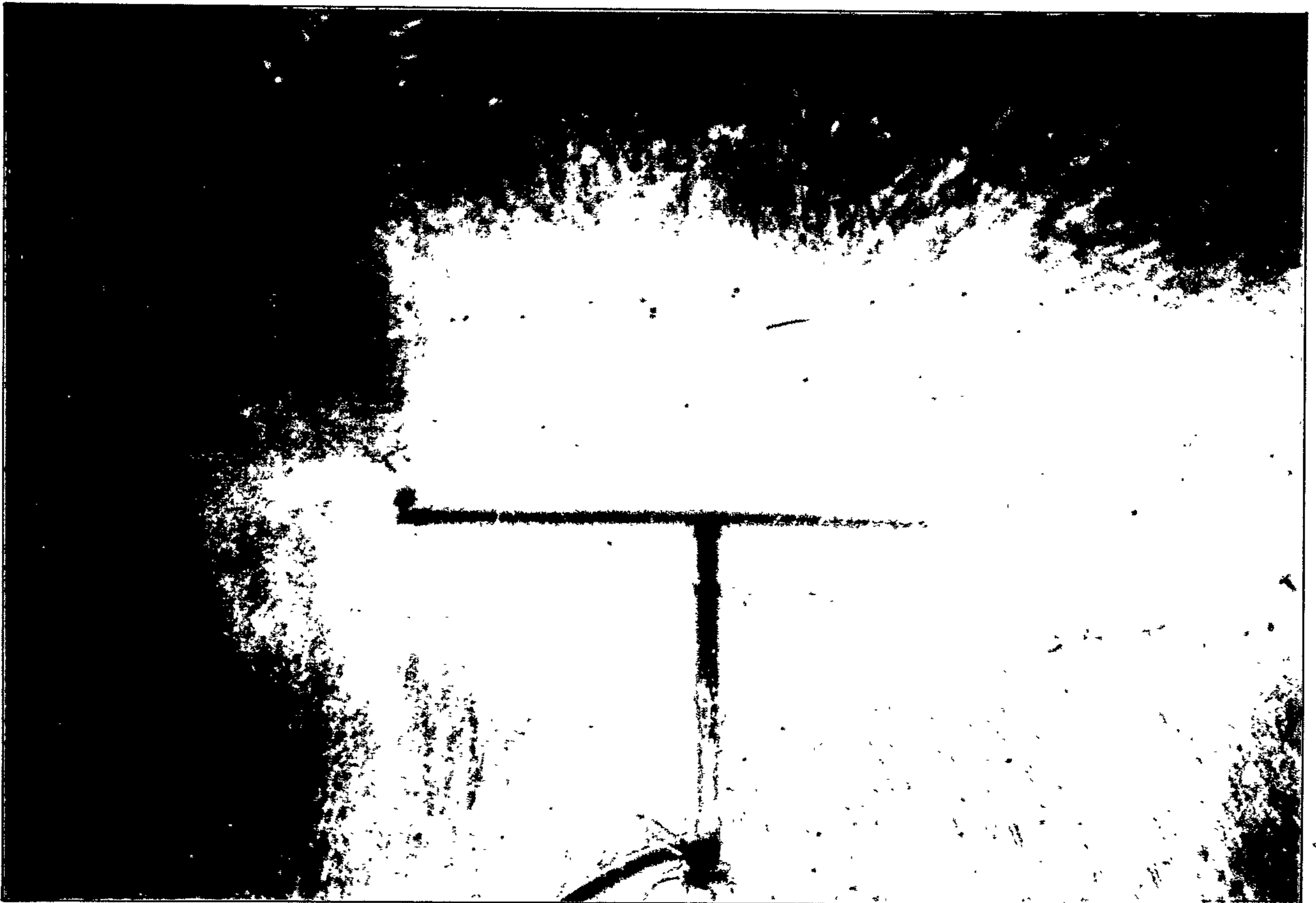
To Mr. David Ma, for his expert typesetting of the tables and the artistic approach to some of the graphic designs.

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To my parents, for their unfailing encouragement and support, during a difficult two years, and their contribution to offset printing most of the illustrations.

We are part of a spray,
We interact
and give off dazzling colors,
then separate.

To my colleagues in the Orthodontic field, for the comradeship we developed, the moments of turbulence we shared, and a memorable two years.



The weariness of flying a lonely path,
the desire of finding a home,
the eagerness of landing.

To my wife, Jennie, in addition to assisting in the typing of the manuscript, was patient and tolerant of the many hours I spent on its preparation.



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Section I

Introduction

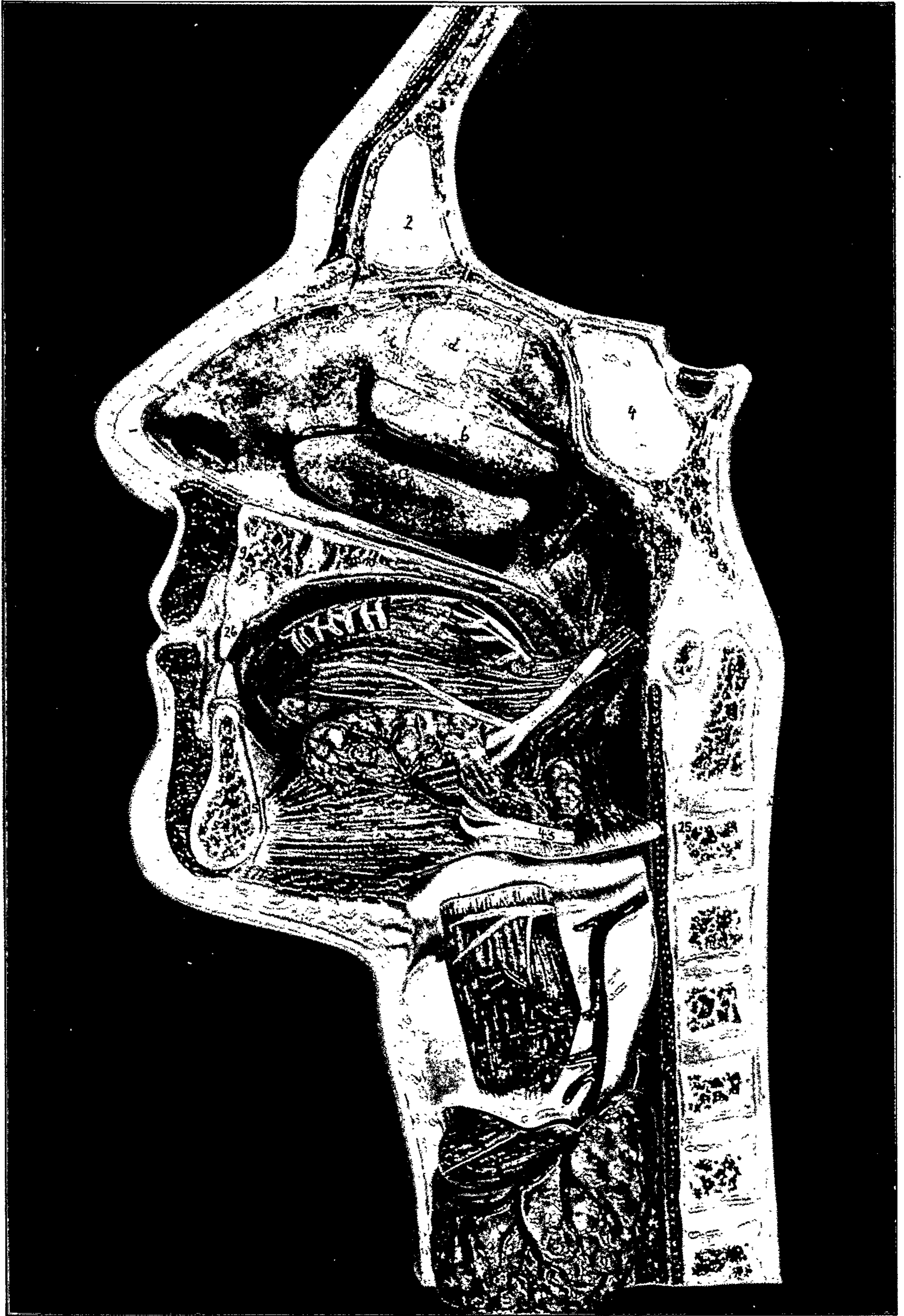


Fig. 1. The human nasopharynx and its relationship to adjacent structures (Author's material)

SECTION I: INTRODUCTION

1. THE PROBLEM

1.1 Form and Function

The problem of form and function has long baffled scientists and clinicians alike. The assumption that form is the resultant of function was regarded by Friel (1926) to be as old as the time of Aristotle, though he conceded that the converse had also been postulated.

While Gesell (1942) stated that 'the fundamental determiners of form are intrinsic, endogenous rather than exogenous', Moss (1962) and Scott (1969) propounded the doctrine of functional matrices as principal components of craniofacial growth.

Lundstrom (1948, 1955, 1959) was able to distinguish between genetic and non-genetic factors, suggesting that most non-genetic modifications developed before birth, and that the precision of the genetic control in a certain external environment may not be absolute.

Whereas Hanson and Cohen (1973) utilised tongue thrust and dento-facial abnormalities to illustrate the enigma of form and function, Graber (1972, p.47) and Moyers (1973, p.113) synthesised a number of theories and concluded that the differentiation of cranial structures is controlled by a few intrinsic genetic factors and by many local epigenetic factors that originate from adjacent structures in the head.

The question of whether form is a resultant of function, or vice versa, is complex and therefore cannot be viewed as merely chicken or egg.

1.2 Nasomaxillary complex, mandible, and growth

The maxillary relation to the skull base as one of the greatest constancies in the growth of the face was noted by Bjork (1950),

supported later by Lande (1952), and again by Brodie (1953). It was seen by Steiner in 1959 for his analysis, and Ricketts (1960) repeatedly verified this constancy in numerous isolated studies.

Similarly, the roof and the floor of the nasal chambers are parts of the larger nasopharyngeal complex which, on an average, was also found to be relatively stable by Vinkka and Koski (1957) in agreement with many previous studies (Zingesser 1960; Bergland 1963; Moss and Salentijn 1969a).

Although Thompson and Brodie (1942) believed in a constancy of the form, proportions and positions of the mandible, Horowitz, Osborne and DeGeorge (1960) observed a large degree of hereditary variability in lower face height. This contention was also supported by Vinkka and Koski (1975), Woodside and Linder-Aronson (1979) who nevertheless found a lesser variability in the length of the mandible.

It is generally agreed, however, that the dimension of the lower face height seems to be more dependent on muscle function, environmental factors interfering with the airway and the posture of the head.

1.3 Respiratory function and dentofacial morphology

The maturation of the oropharyngeal region has been regarded by Bosma (1963a; 1963b) to be closely related to accomplishing a patent pharyngeal airway and to participating in postural functions of the head and neck.

The former notion had indeed been proposed by Todd (1932) who realised that vertical facial growth was largely determined by body respiratory needs, and by Moss and Salentijn (1969b) who pointed out that the shape and size of the respiratory pathway is dependent on the functional volumetric demands involved in respiration.

More recently, Martens (1979) looked upon the intake of air as a survival factor, and in cases of airway blockage, compensation is achieved by alteration of breathing and musculature pattern, hence producing malocclusion. Thurow (1973) even showed a need to trace in the airway during routine cephalometric analysis, though he cautioned that it only depicts structures in one plane.

The hypothesis by Shelton and Bosma (1962) that maintenance of the airway can be viewed as being effected by interaction between cervical postural and pharyngeal muscles was verified by Harvold, Vargervik and Chierici (1972; 1973) who showed a consistent lowering of the mandible in experimentally-induced mouth breathing monkeys, and later by Vig, Showfety and Phillips (1980) who demonstrated a progressive extension of the head posture in experimentally-induced nasal obstruction subjects.

Furthermore, Woodside and Linder-Aronson (1979) found in a group of children requiring adenoidectomy a more extended head-posture which disappeared one month after surgery.

It is therefore conceivable that a type of cause-effect relationship may exist between respiratory function as determined by nasal respiratory patency and certain dentofacial morphology in a manner explained.

1.4 Adenoid facies

Adenoids, a type of lymphatic tissue in the form of nasopharyngeal tonsil as part of Waldeyer's ring, have long been regarded as one of the chief causes of mouth breathing (Backlund 1963). Such a phenomenon occurs mainly during preschool and early school years because the adenoids frequently hypertrophy at a rate which exceeds the growth increment of the nasopharynx, occluding almost the total nasopharyngeal space (Handelman and Osborne 1976). Subsequent adenoidal involution, however, accounts for a decrease in mouth breathing observed in older children and adolescents noted by Subtelny (1954).

The importance of adenoids, therefore, lies in its ability to physically restrict the nasopharyngeal space, rendering a decrease in nasal patency. Various methods have been devised to quantify either the adenoids or the nasopharyngeal space on a lateral cephalometric radiograph, despite the inherent error of the one-plane nature of the measurements.

Admitting the inadequacies of unsubstantiated radiographic quantifications, it has nevertheless been shown that a diminished two-

dimensional nasopharyngeal space is statistically correlated with incidence of mouth breathing (Schulhof 1979).

A particular facial expression, moreover, is said to be typical of individuals with adenoids and mouth breathing. The following description, generally agreed by many (Ricketts 1968; Linder-Aronson 1970; et al), but refuted by some (Sillman 1942; Hartsook 1946; et al) to be of significance, is loosely termed 'adenoid facies':

"The mouth stays open, the nose appears flattened, the nostrils look small and underdeveloped, the upper lip short, the lower lip thick and everted, and - especially due to the half-open mouth - the individual has a vacant stupid expression. The dentition is stated to be of a special type, consisting of protruding upper incisors, a narrow V-shaped upper jaw with a high palatal vault, and a post-normal relation between the upper and lower jaws". (Linder-Aronson 1970, p.5).

In fact, the term 'adenoid facies' is not an entirely satisfactory nomenclature. It does not indicate the etiology associated with the syndrome, even some characteristics included under the name were disputed upon. Linder-Aronson (1970), for example, regarded retroclination of upper and lower incisors as typical of 'adenoid facies' rather than protrusion of upper incisors.

2. THE QUESTION

Given that an alteration in mandible and head postures can be experimentally induced (Harvold et al 1972; Vig et al 1980), and that certain features of the dentition or shape of the jaws can be influenced by muscular forces or habits (Ricketts 1958a), how valid can one apply these observations to the occurrence of adenoids, mouth breathing, and a particular facial expression and type of dentition?

3. THE CURRENT STATE OF THE ART

The issue of nasopharyngeal conditions and dentofacial morphology covers a wide scope overlapping dental and medical specialties. Specifically, nasopharyngeal conditions identify the occurrence of adenoids, the relative size of nasopharyngeal airway, and a degree of nasal obstruction. Dentofacial morphology, in this respect,

includes those characteristics associated with 'adenoid facies', and said to be accompanied by mouth breathing.

A brief survey of literature reveals an assertion of an association (be it cause-effect or coincidental) among some components of the following chain, which for convenience, shall be called 'Adenoid Facies Path' in this study:

Large Adenoids (small nasopharyngeal space)
Nasal Obstruction (Diminished nasal respiratory patency)
Mouth Breathing (Altering orofacial musculature activities)
Adenoid Facies

In the past, studies were carried out to find an association (or dissociation) between adenoids and nasal obstruction (Gray 1977); or nasal obstruction and mouth breathing (Subtelny 1975); or adenoids, mouth breathing and adenoid facies (Ricketts 1968); and so on.

In most investigations, exact quantification of nasopharyngeal dimensions were either not done, or not possible to be done. Rarely was degree of nasal obstruction accurately assessed. Few longitudinal studies were conducted, and even fewer involving pre- and post-adenoidectomy observations.

The original research in 1970 and a series of follow-up studies performed by Linder-Aronson pioneered the trend to look for means to substantiate and explain findings in frequency observations in this field. Using a standardised form of evaluating adenoids and nasal airway patency, Linder-Aronson investigated a total of 161 children half of which underwent adenoidectomies, and concluded that *'adenoids affect the mode of breathing, which then influences the individual's dentition'* (Linder-Aronson 1970, p.126).

Like other studies, no attempt was made to justify the validity of the radiographic quantification of nasopharynx used at the time. Granting a close association found between radiographically assessed adenoids (or nasopharyngeal space), nasal obstruction, mouth breathing, and 'adenoid facies', any causal theory derived must be built on a weak premise unless the radiographic assessment could be proven to be a valid indicator of the actual, irregularly shaped, dynamic

and three-dimensional nasopharyngeal space.

It is this basic but overlooked supposition that prompted the present investigation. Undoubtedly it was nearly impossible to accurately assess nasopharyngeal volume, but with the advent of Computed Tomography which has already been proven useful in evaluating body spaces, this primary problem can perhaps be solved.

4. THE HYPOTHESES

- (1) Certain groups of measurements denoted on a lateral cephalometric radiograph are valid indicators of the actual size of nasopharyngeal space.
- (2) There is a substantial relationship between the size of nasopharyngeal space, upper airway patency, and mode of breathing with specific characteristics of dentofacial morphology.

5. TESTING THE HYPOTHESES

It is felt that the following tests are required to provide evidence to support the hypotheses:

- (1) Development of a standardised, reproducible and non-invasive method to accurately assess the dimensions of nasopharyngeal space.
- (2) After procuring values of various radiographic measurements in use to quantify nasopharyngeal space and their respective actual volumes, the relationship between them can be statistically tested.
Subjects so tested should ideally be free of nasopharyngeal pathology, of varying age groups and comprise of large groups.
- (3) The measurement or groups of measurement showing a strong statistical relationship with actual volumes can be regarded as valid indicators.
- (4) Using the derived method of measurement, the 'Adenoid Facies Path' can be effectively tested on large samples for possible relationship.

- (5) To properly test the hypotheses, long term studies are needed involving experimental and control groups. Comparison between pre- and post-adenoidectomised subjects is essential to assess changes in mode of breathing and dentofacial morphology following an increase in size of nasopharyngeal space.
- (6) By employing this *modus operandi*, any association between the variables can be exposed, and a possible cause-effect relationship asserted.

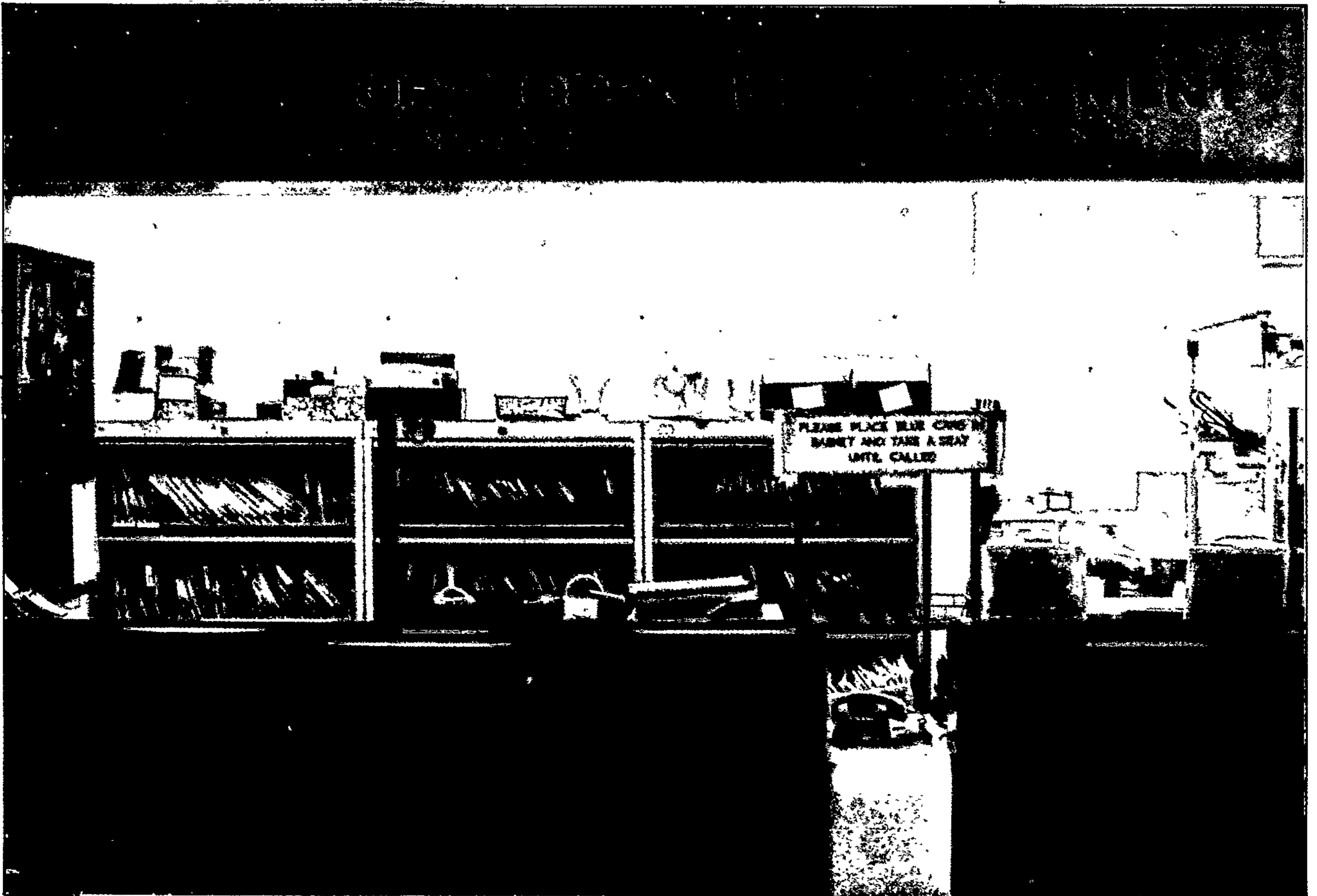
Section II

Review of the Literature

SECTION II: REVIEW OF THE LITERATURE

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Fig. 2. Orthodontia Department, University of Sydney



CHAPTER 1: INTRODUCTION

The following review is the result and sublimation of a research of literature pertaining to the suggested hypotheses. Efforts were directed to obtain comprehensive information that provides the background and apparatus to examine the hypotheses. Because of the strong medical flavour inherent in this topic, authoritative representations from both dental and medical fields are incorporated.

The arrangement of chapters are designed to enable the reader to appreciate the complexity and controversial aspect of the nasopharyngeal region, to expose the inadequacies of previous findings, to assemble materials upon which a working hypothesis can be constructed, and perhaps further questions raised.

Chapter 2 reports on the basic morphology and developmental interplay of components of nasopharynx with parts of the craniofacial skeleton.

Chapter 3 looks at the history and development of examining the nasopharynx, the advantages and disadvantages of each method, and endeavours to assess the accuracy achievable.

Chapter 4 relates some forty methods suggested by previous dental and medical authorities to radiographically quantify nasopharynx, describes the usage of such evaluations, appraises the relative validities of these methods, and identifies the most acclaimed ones to be used for testing.

Chapter 5 provides the background of Computed Tomography and its eventual capacity to be used in volumetric evaluations.

Chapter 6 not only explores the different ways to estimate upper airway patency, but discusses a simple method which a clinician can easily operate. This method will be applied in experimental studies that follow.

Chapter 7 researches the causes and sequelae of nasal obstruction, and its relation to nasopharyngeal obstruction.

Chapter 8 identifies the causes of mouth breathing, and critiques

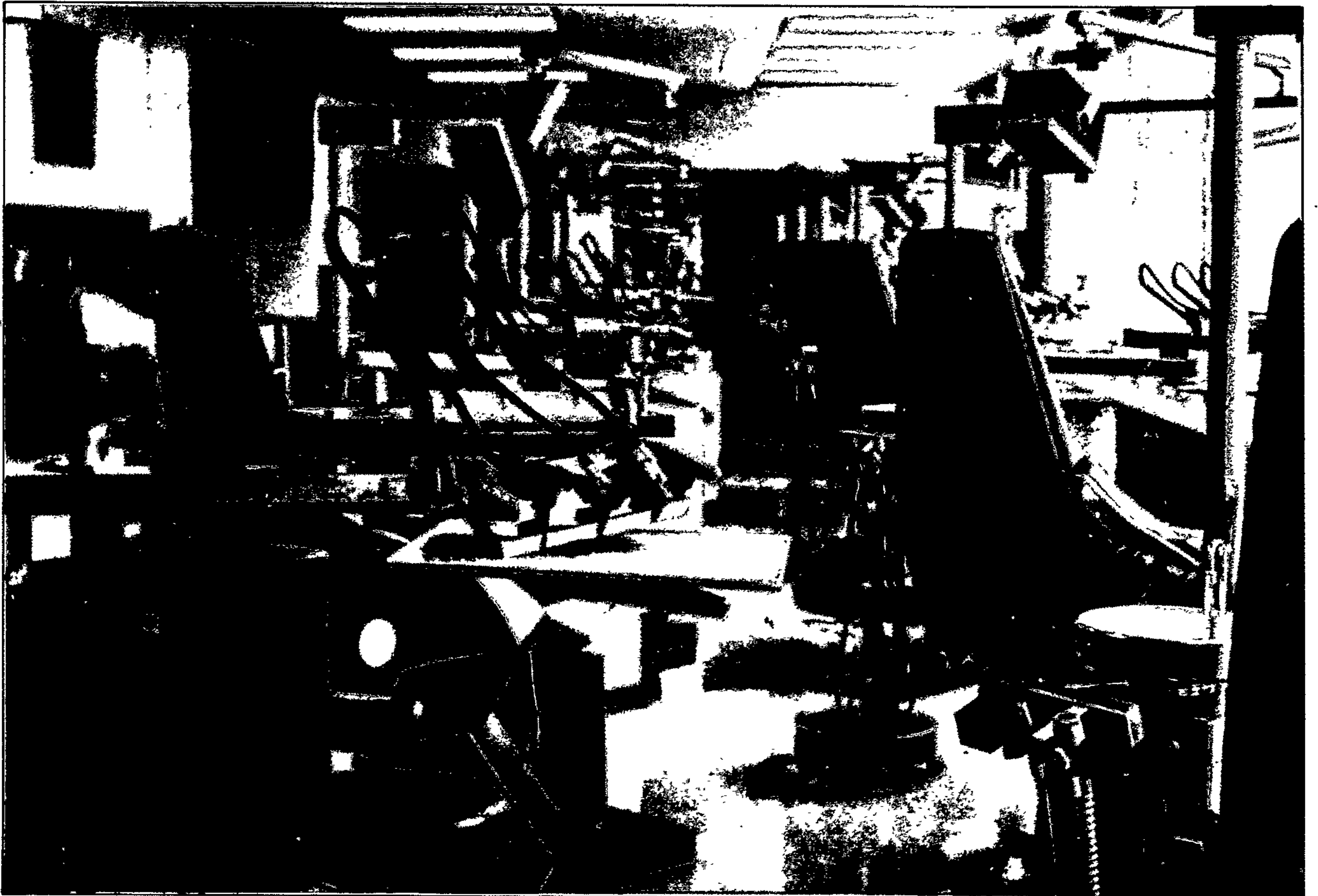
the evidences put forward by a multitude of authors for or against the cause-effect relationship of adenoids, nasal obstruction, mouth breathing, and dentofacial anomalies (i.e. the 'Adenoid Facies Path').

It is hoped that such a step by step presentation of information will present materials whereby an experiment can be constructed and a plan contrived to test part, if not the whole, of the hypotheses.

CHAPTER 2: ANATOMY, GROWTH AND DEVELOPMENT OF THE HUMAN NASOPHARYNX

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Fig. 3. Orthodontic clinic, United Dental Hospital



CHAPTER 2: ANATOMY, GROWTH AND DEVELOPMENT OF THE HUMAN NASOPHARYNX

2.1 NOMENCLATURE

The term 'pharynx' was first introduced by Galen (130) to denote that portion of the digestive tube connecting the mouth to the stomach, while Vesalius (1543) substituted the word 'oesophagus' for Galen's pharynx. During the eighteenth century, this Galenic notion of the pharynx as a single muscular tube connecting mouth and stomach was replaced by the modern idea of a separate pharynx and oesophagus.

In current textbooks, a further subdivision of pharynx into nasopharynx, oropharynx and laryngopharynx is found (Grant and Basmajian 1965), and the nasopharynx is described as:

"The upper portion of the pharynx lying above the soft palate and behind the nasal cavity and communicating with the oropharynx inferiorly through the nasopharyngeal isthmus or hiatus" (Leela, Kanagasuntheram and Khoo 1974, p. 333).

Weitz (1946) believed that the nasopharynx is exclusively respiratory in function; the oropharynx both respiratory and alimentary; and the laryngopharynx almost entirely alimentary.

Wood Jones (1940) on the contrary regarded nasopharynx as part of the nasal fossa rather than the pharynx proper, while Lambert (1960) argued that it is non-nasal because it is posterior to the nasal fossa proper, and advocated the term 'post-nasal space' for the nasopharynx.

Cave (1960) observed that the nasopharynx belongs neither to the food tube nor the nasal fossa, but is a part of the respiratory passage in its own right, and therefore he preferred the term 'epipharynx' for this region.

In an endeavour to resolve this confusion of nomenclature, Leela et al (1974) studied specimens of primate and human nasopharynx on a macroscopic and histological scale. They concluded that the nasopharynx appears to be composed of an anterior 'nasal' and a posterior true 'pharyngeal' portion, the junction between the two occurring at about the level of the tubal orifices where the first and

third pharyngeal arches meet in embryonic life. It was therefore recommended to regard the nasal cavity as extending back to the level of the tubal orifices and the pharynx proper as commencing about the level of the tubal orifices.

For the purpose of this study, however, the term 'nasopharynx' will be consistently used since it describes the region morphologically and is a term most widely adopted in literature.

2.2 EMBRYOGENESIS

According to Griffin and McGrath (1978), the nasopharynx as a definitive region becomes evident in the later part of the embryonic stage when the cranial end of the foregut dilates to form a primitive pharynx underlying the posterior part of the development chondrocranium.

The embryogenesis of nasopharynx, for the purpose of this study, will be described only briefly and is considered in terms of the bony nasopharynx and the soft tissues which line it.

The bony nasopharynx is formed by elements of the neurocranium and the visceral cranium, and the developmental processes of these two regions will determine its shape and capacity.

The cranial base forms the roof and the greater part of the posterior wall of the nasopharyngeal cavity and the flattening of the cranial base over the prenatal period tends to increase the sagittal depth of the cavity.

De Beer (1971) observed that flexion of the cranial base is evident in the 10th week of foetal life but the effect is somewhat disguised by the concurrent increase in the sagittal height of the posterior border of the vomer and the medial pterygoid plates. As a result, during the period at 18 weeks to 40 weeks, the angle of flexion of the cranial base increased about 8 degrees but the roof of the nasopharyngeal cavity only opened up 3 degrees.

It was also noted by Griffin and McGrath (1978) that the shape and

capacity of the bony nasopharynx as viewed in the coronal plane are determined by the increase in height of the medial pterygoid plates between 18 and 28 weeks, the increase in width of the sphenoid over the final weeks of foetal life and the position of post-nasal apertures. At birth, the nasopharyngeal cavity in the coronal plane is seen to be low and wide.

The soft tissues of the nasopharynx arise from the endoderm of the cranial end of the foregut, from the mesodermal condensations of the pharyngeal arches and, in the instance of the pharyngeal hypophysis, from the ectoderm of the stomodaeum. The site of the opening of the pharyngo-tympanic tube relative to the hard palate arises with the growth of the bony walls and the development of a respiratory epithelium lining the nasopharynx is completed in the later part of foetal life.

While Griffin and McGrath (1978) suggests that development of the pharyngeal hypophysis, a collection of adenohypophysial tissue in the roof of the nasopharynx, appears to be completed in the perinatal period, Morag and Ogra (1975) suggest that these tissues develop from the second pharyngeal pouch in close proximity to developing embryonic thymus.

Sperber (1976), on the other hand, believes that the palatine tonsils arise at the site of the 2nd pharyngeal pouch, while the adenoids and lingual tonsils develop in the mucosa of the posterior wall of the pharynx and the root of the tongue respectively.

It is also evident that any disturbances in embryogenesis, in particular of the cranium, may result in anomalies of the nasopharynx. Examples of such are seen in the gross congenital malformations known as anencephaly, or cranioschisis, and iniencephaly, and in cases presenting with restricted median cranial vault deficiency.

Choanal atresia, which can be bony or membranous, is also a congenital cause of nasal obstruction (Rubin 1979).

2.3 GROSS ANATOMY

2.3.1 Bony Nasopharynx

According to Schuller (1929) and Goldman and Bachman (1958), the bony nasopharynx is delineated by five bony boundaries:

- (1) Roof is formed by the basisphenoid and basiocciput (Fig. 4, 5);
- (2) Posterior wall by the condyloid portion of the occipital bone and the adjacent anterior arch of the atlas;
- (3) Anterior boundary by the vomer and choanae;
- (4) Laterally by the right and left medial pterygoid plates.

Bergland (1963), however, viewed the bony nasopharynx as bordered by the following skeletal elements:

- (1) Anteriorly, the structures constituting the choanal apertures, i.e. the medial plates of the pterygoid processes laterally and the dorsal border of the vomer medially;
- (2) Posteriorly, the pharyngeal surface of the body of the sphenoid bone and of the basilar part of the occipital bone;
- (3) Caudally the bony nasopharynx is limited anteriorly by the posterior border of the horizontal part of the palatine bone and posteriorly by the anterior margin of the foramen magnum.

Geometrically the bony nasopharynx in the median sagittal plane is shaped like a gable (Fig. 6). The anterior part of the gable, corresponding to the choanal structures, is formed by a line joining the landmarks Staphylion, i.e. posterior nasal spine, and Hormion, i.e. the vomer's dorsorostral point at contact with the body of the sphenoid bone. In Man, this line is approximately parallel to the main direction of the pterygoid process, i.e. the choanal plane (Ecker 1870).

The posterior part of the gable, corresponding to the caudal surface of the body of the sphenoid bone and the basilar part of the occipital bone, is formed by a line joining the above-defined point Hormion and the point Basion, i.e. the anterior margin of the foramen magnum. The region Hormion-Basion has been referred to as the pharyngeal clivus (Bergland 1963). The bony nasopharynx is caudally limited by a line joining the points Staphylion and Basion.

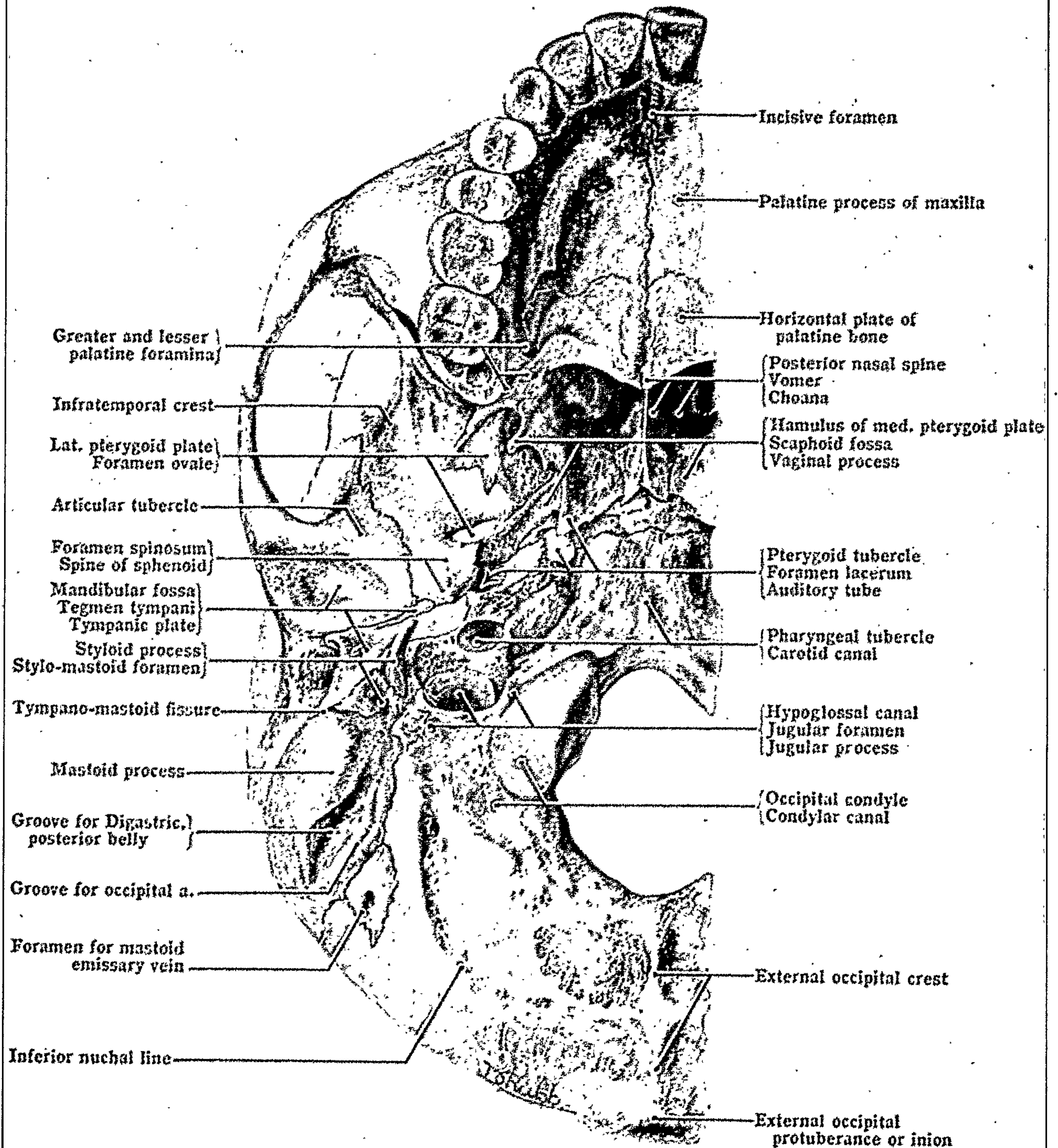


Fig. 4. Exterior of the base of skull
(From Anderson 1978, p. 9-47)

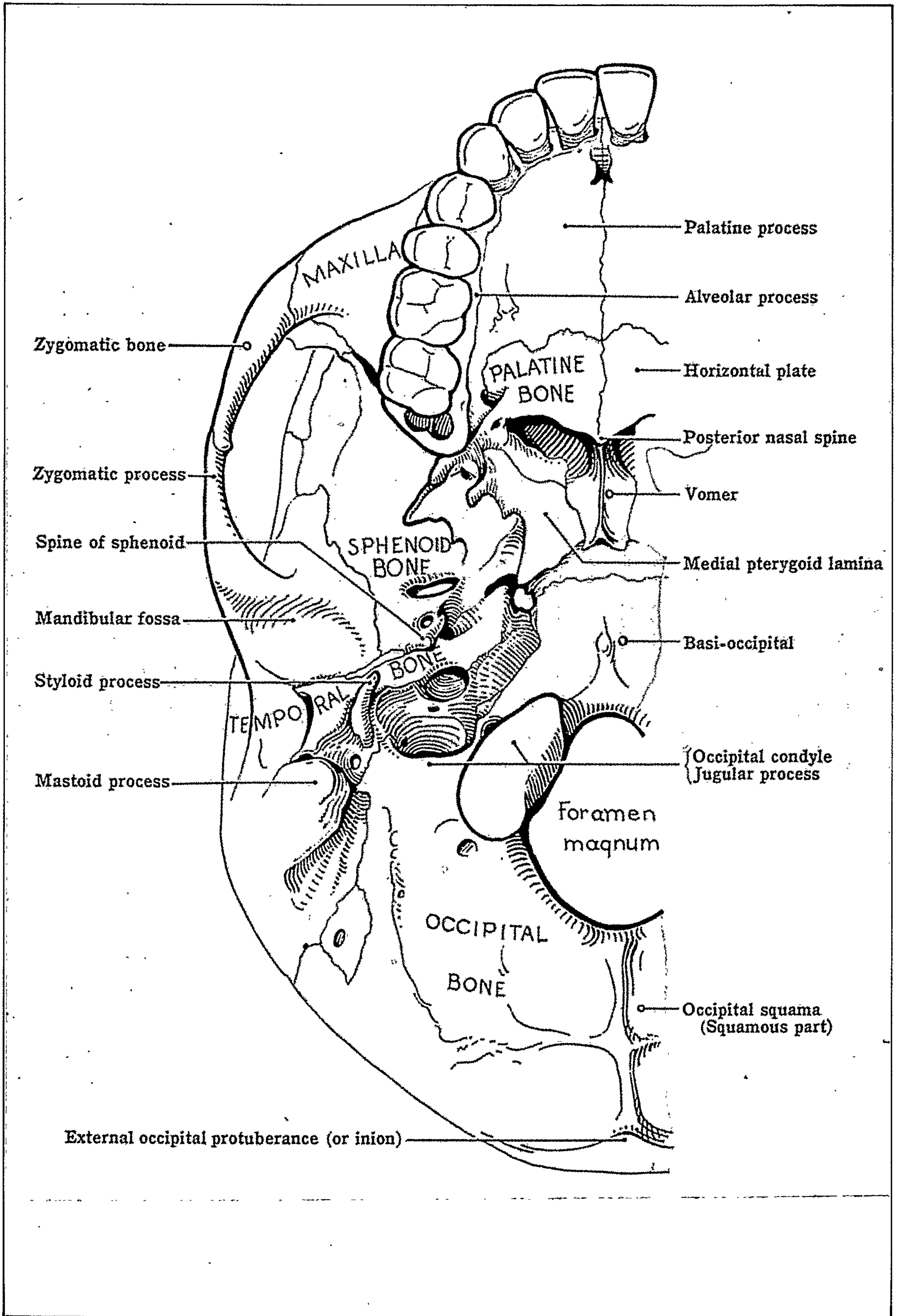
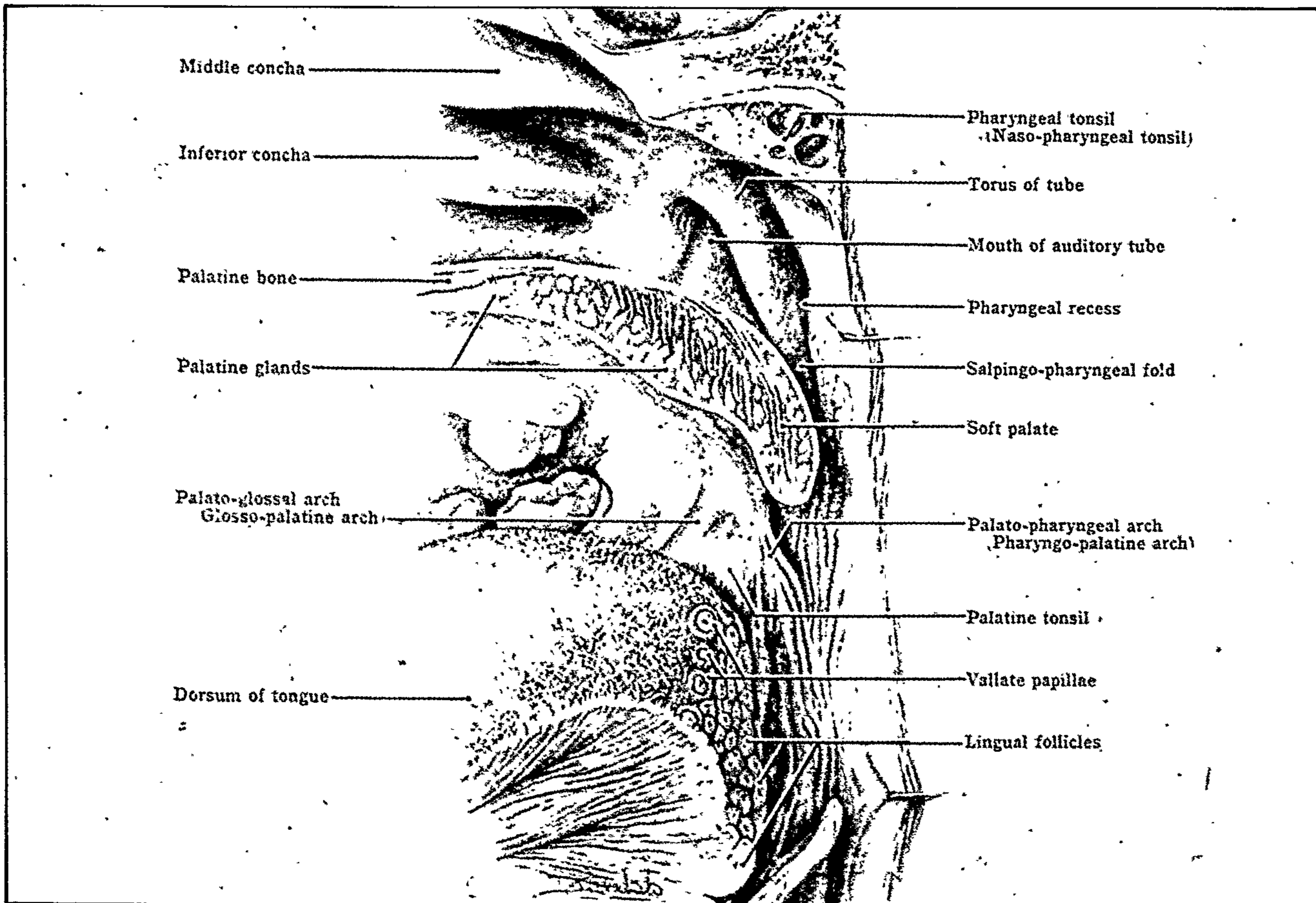


Fig. 5. Bones of the exterior of the base of the skull
(From Anderson 1978, p. 9-48)



Fig. 6. Side of skull showing 'gable' form of bony nasopharynx (Author's material)

Fig. 7. Interior of nasopharynx, side view (From Anderson 1978, p. 9-57)



The bony width of nasopharynx, however, is hard to define. The greatest width of the choanal openings is usually taken as the greatest distance between the medial pterygoid plates, and this is usually situated midway between the upper and lower border of the choanal openings.

Goldman and Bachman (1958) described a form of roof arch in some patients where the anterior flattening thereof causes a diminished supero-inferior diameter. Although it can be compensated posteriorly by marked depression of the soft palate, the anterior region just behind the choanae cannot, and is regarded as a 'critical region', important but hard to explore.

Schuller (1929) classified deformities of bony surroundings of the nasopharynx into three groups:

- (1) All forms of narrowing due to shortening of skull base. This may be congenital or acquired, exemplified by a decreased basal angle associated with chondrodystrophy, or excessive lying on the back, accentuating the curvature of posterior cranial fossa so that the posterior pharyngeal wall more vertically oriented.
- (2) Congenital or acquired deformities in the region of the upper cervical vertebrae. Narrowing in the sagittal dimension may occur.
- (3) Craniostenosis characterised by the marked downward protrusion of the body of the pterygoid bone. Shortening of the vertical dimension may result.

2.3.2. Soft tissue linings

While Khoo, Lee, Ng and Tye (1974) recognises the great variations in size and shape of the soft tissue nasopharynx, Jing (1970) describes it as having five walls and communicates with the oropharynx through the pharyngeal isthmus. The five walls are:

- (1) The anterior wall is formed superiorly by the choanae and the posterior surface of the nasal septum.
- (2) Inferiorly bounded by the soft palate. Communications with the nasal cavities is effected through the choanae and is in close relationship to the posterior aspect of the middle and inferior turbinates of the nose.

- (3) The roof and posterior wall form a continuous slope which is opposite a portion of the sphenoid, the basisphenoid, and the basiocciput, and the upper two cervical vertebrae. In the roof, the mucous membrane is thrown into numerous and variable folds with lymphoid tissue constituting adenoids or pharyngeal tonsil. In the supero-posterior midline, near the lower end of the adenoids, there is an inconstant small, blind sac, the pharyngeal bursa. More anteriorly, a pharyngeal hypophysis, derived from the pharyngeal end of Rathke's pouch, is usually present.
- (4) Laterally, the posterior wall contains the pharyngeal orifice of the Eustachian tube. The orifice is somewhat triangular in shape and is bounded superiorly and posteriorly by a prominence, the torus tubarius, which is produced by the salience of the medial end of the cartilage of the tube. The depression formed behind the torus tubarius is the pharyngeal recess, or fossa of Rosenmuller. Deep to the mucous membrane, the roof of the nasopharynx is firmly attached to the base of the skull by the pharyngeal aponeurosis.

The above anatomic features are diagrammatically represented by Anderson (1978) as illustrated in Figs. 7, 8, 9.

McCarthy (1925) noted that all these walls merge together and that any exact division is impossible. He also regarded that the nasopharynx is different from the rest of the pharynx in that all of its walls are immovable, except the floor, so that the cavity cannot be obliterated.

On the other hand, Khoo, Chia and Nalpon (1967) using cinefluorography, and Skolnick, Zagzebski and Watkin (1975) employing ultrasonic scanning equipment were able to illustrate the appreciable degree of expansion and contraction of the lateral walls during deglutition, thus indicating a great degree of pliability of these walls.

Furthermore, Leela, Kanagasuntheram and Khoo (1974), again executing cinefluorographic techniques, showed that the contractility of the human nasopharynx is confined to that portion which lies at and behind the tubal orifices, the morphological delineation of nasal and pharyngeal components of the nasopharynx.

It is therefore not surprising to find that proximal to the tubal

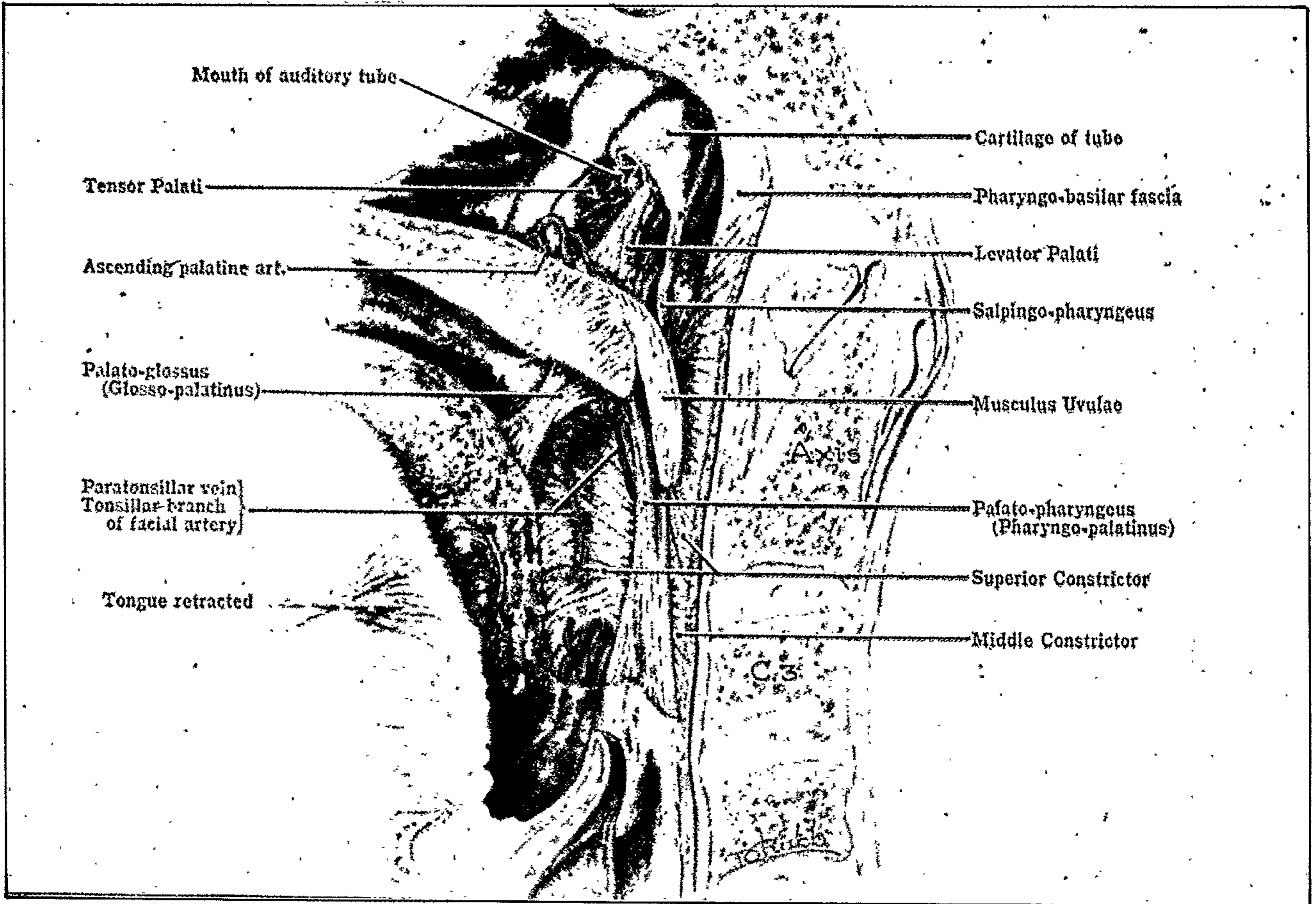
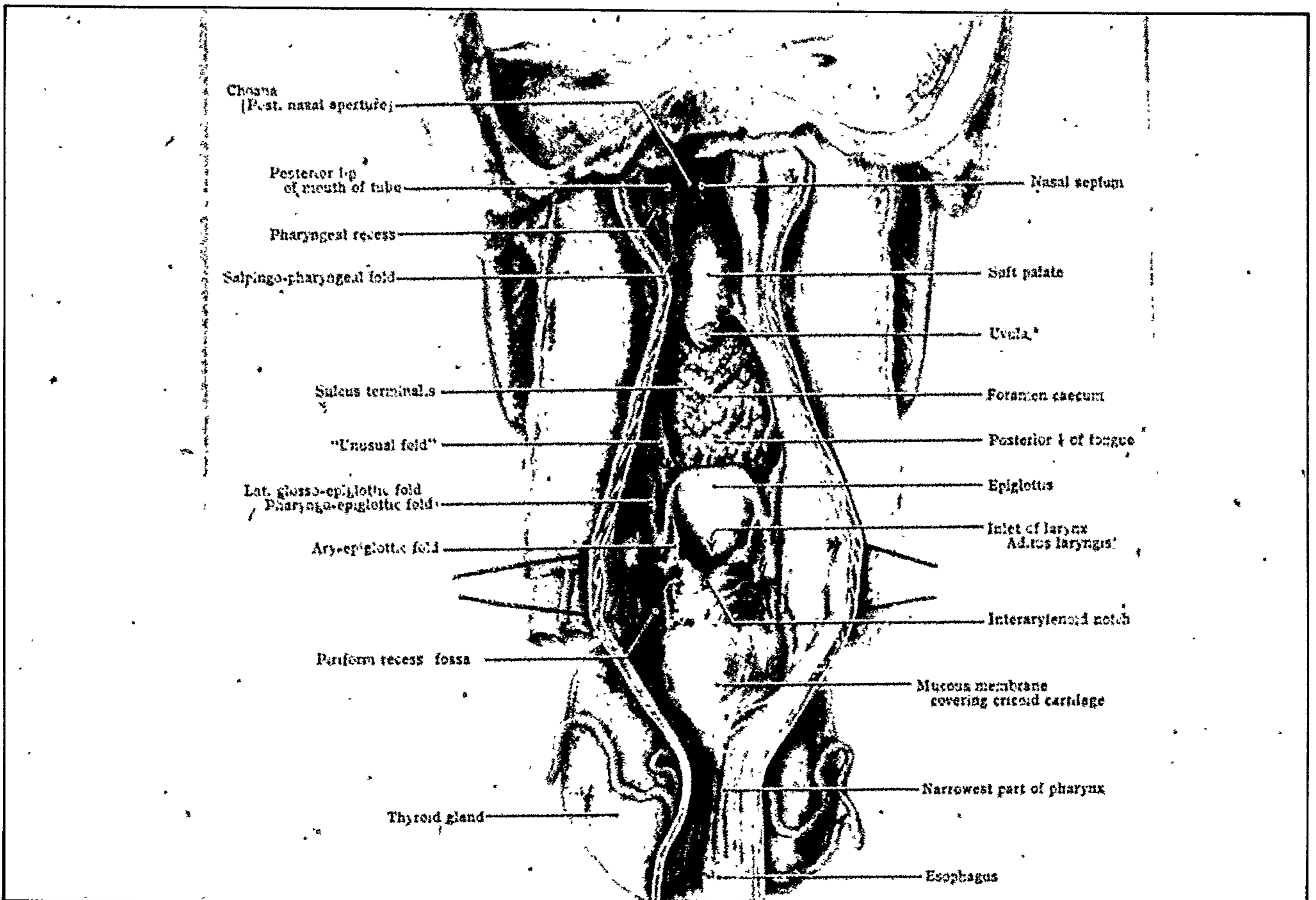


Fig. 8. Interior of nasopharynx dissected, side view
(From Anderson 1978, p. 9-58)

Fig. 9. Interior of nasopharynx, from behind
(From Anderson 1978, p. 9-56)



orifices, the innervation is from branches of the maxillary division of the trigeminal nerve, while the portion behind the tubal orifices was supplied by the glossopharyngeal nerve (Kanagasuntheram, Wong and Chan 1969). While the nasopharynx is richly supplied by simple nerve terminations, a copious lymphatic capillary network is also present, the collecting trunks usually drain into the ipsilateral nodes or directly into the spinal accessory chain (Jing 1974).

The variability of the nasopharynx is further substantiated by Khoo, Kanagasuntheram and Chia (1967) who reported large outpouchings or diverticulum-like hollowing of the lateral recesses (i.e. fossa of Rosenmüller) present in 40 per cent of contrast cinefluorographic studies. It was also explained that these pouches manifest themselves later in life because of the natural regressions of pharyngeal tonsils.

As early as 1925, Testut and Jacob were able to understand the variability of nasopharynx, and described three principal forms of the pharyngeal arch as:

- (1) Angular arch, in which the roof of the pharynx slants backwards and downwards forming a blunt angle with the posterior wall, lying high above the palate.
- (2) Rounded arch, the roof lies at a medium height.
- (3) Low arch, and is characteristic of childhood. The space is low with the pharyngeal arch at the level of the inferior turbinate and the tubal openings at the level of the palate.

2.3.3 Adenoids and soft palate

Devgan and Leach (1979), in a study to assess adenoidal hyperplasia, reported that adenoids are more correctly referred to as nasopharyngeal tonsil, which is a single midline mass situated in the roof of the nasopharynx and forms a part of the Waldeyer's ring (Fig. 10). They also remarked that the word 'tonsil' is derived from the Latin word 'tonsilla', a mooring post, and 'adenoids' from the Greek word 'aden' (gland) and 'eidos' (form).

It is of interest to note that the term 'hyperplasia' is used by some authors to describe overgrowth of adenoids, though the term 'hypertrophy' is generally preferred and probably more accurate.

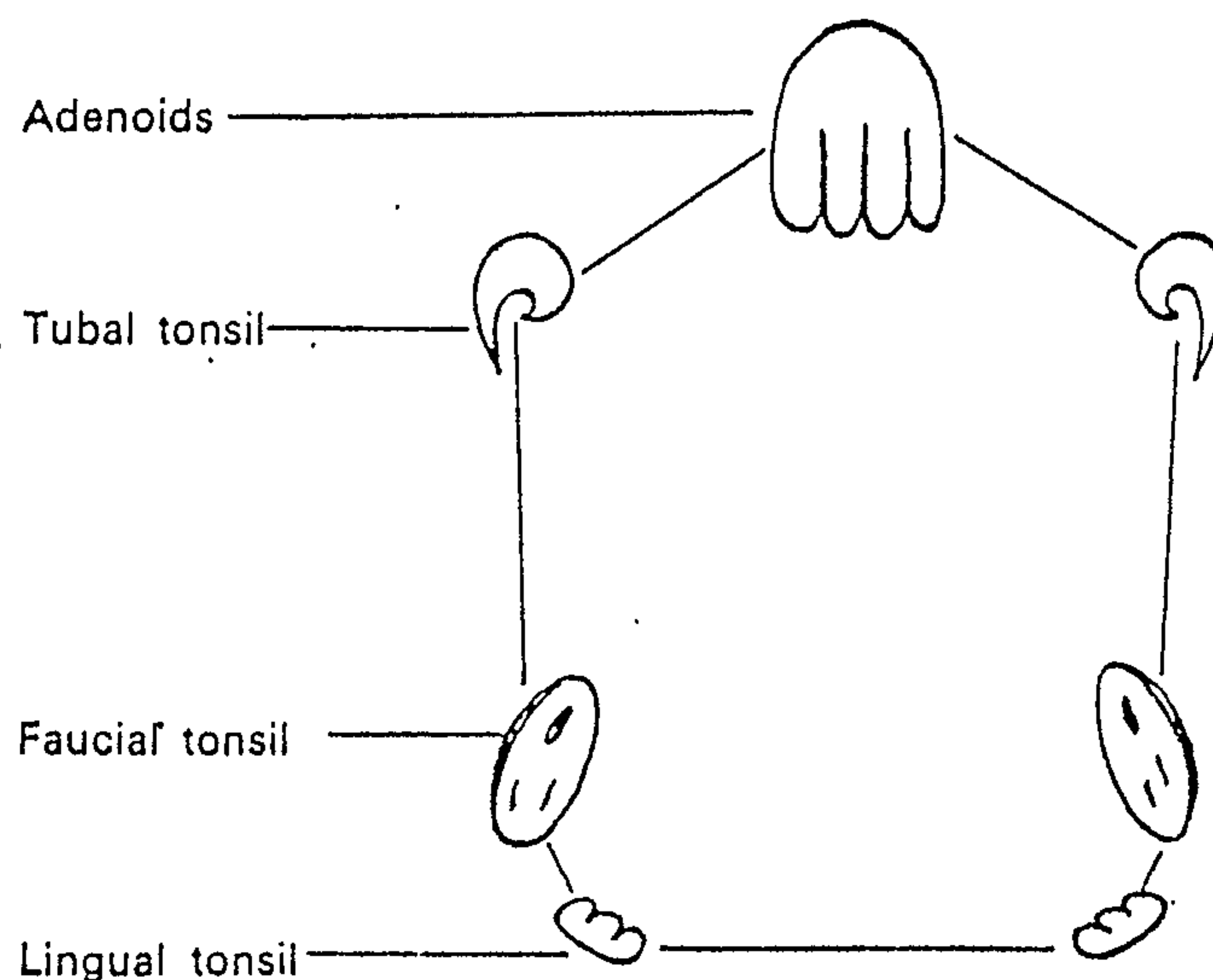


Fig. 10. The Waldeyer's Ring (From Devgan and Leach 1979)

While Jing (1970) recorded adenoids as posterior to pharyngeal hypophysis and anterior to pharyngeal bursa, Grandy (1925) had already illustrated from Cunningham's Textbook of Anatomy that:

"Upon the roof-posterior wall of the pharynx, down to the level of the anterior arch of the atlas and extending laterally as far as the Eustachian orifices is a collection of adenoid tissue, the pharyngeal tonsil. Hypertrophy of this tissue constitutes the condition known as 'adenoids' the harmful effect of which are due to their interference with the nasal respiration" (Grandy 1925, p.114).

Subtelny and Baker (1956) described adenoids in the mid-sagittal plane of the head as:

"It usually appears as a somewhat convex prominence facing the superior surface of the soft palate. It is attached to both the roof of the nasopharynx and the posterior pharyngeal wall. The lymphatic tissue attached to the roof extends anteriorly almost to the anatomic location of the posterior choanae and encroaches upon the posterior superior aspect of the vomer bone. When the convex prominence of the adenoid tissue is visible on the x-ray film, its anterior border is seen to extend downward from the roof, approaches the soft palate, and extends inferiorly up to or slightly below the level of the anterior tubercle of the atlas" (Subtelny and Baker 1956, p.236).

Although the appearance of adenoids on radiographs is characteristically a rounded anterior segment and a posterior straight part, differential diagnosis is sometimes hard and tissue biopsy may be required to distinguish it from other tumors (Jing 1970). Sometimes a morphological variation like a projection of the body of a vertebra on the posterior wall may be misleading (McCarthy 1925).

The morphologic appearance of adenoids is, nevertheless, diagnostic and Weitz (1946) noted it as:

"Numerous folds which contain much lymphoid tissue, both diffuse and in the form of numerous characteristic nodules with crypt-like invaginations of the surface epithelium" (Weitz 1946, p.66).

The soft palate, on the other hand, is a dynamic component of nasopharynx. When the patient is not phonating or swallowing, the soft palate is seen to be pendant and about 1 cm from the posterior pharyngeal wall (Weitz 1946). During swallow or phonation, the soft palate becomes active, contracts and elevates, tending to encroach upon the nasopharynx and to obstruct communication between the oropharynx and nasopharynx.

Ricketts (1954) demonstrated that during velopharyngeal closure, the palate is actually elevated near its center, brought upwards and backwards by the Levator Veli Palatini muscles which take origin near the ends of the petrous portion of the temporal bone and run medially downward and forward to be inserted into the back of the soft palate, joining at the midline. The lateral sides of the velum blend with muscles of the pharynx and the tongue. These muscles, particularly the palato-pharyngeus, offer resistance during this action and the resultant is a characteristic hooking action seen in cinefluorographic methods.

2.4 GROWTH AND DEVELOPMENTAL INTERACTIONS

The shape and capacity of the nasopharynx as determined by its bony walls undergo progressive growth into adulthood. The functional capacity of the nasopharynx as part of the respiratory system, however, is also dependent on soft tissue elements, notably the adenoids, of its walls.

As stated by Subtelny (1975), growth of the nasopharynx and adenoids seems to strike a fine state of balance. A discussion on development of this region relies on how nasal respiration is dependent on capacity of soft tissue nasopharynx, which is affected by adenoids internally and limited by the bony nasopharynx externally, which in turn is determined by growth of adjoining bones.

2.4.1 Bony nasopharynx

The nasopharynx comes to lie immediately posterior to the nasal cavities and antero-inferior to the posterior part of the cranial base. It is therefore possible that the capacity of the nasopharynx at different developmental stages is to a great extent determined by the dimensions and interrelationships of the elements of the bony nasopharynx formed by the posterior part of the cranial base and the posterior nasal apertures (Griffin and McGrath 1978).

Assessment of bony nasopharyngeal growth can be defined by depth and height in the median sagittal plane, width in the frontal plane, and volumetric capacity.

2.4.1.1 Depth

Schuller (1929) suggested a positive correlation between the cranial base angle and nasopharyngeal depth, an idea supported by many (Ricketts 1954; Wildman 1961; et al) and refuted by some (Engman, Spriestersbach and Moll 1965; Schweiger 1966; et al). He also suggested the use of posterior choanae and atlas as antero-posterior delineation, a notion accepted widely still (King 1952; Griffin and McGrath 1978).

It is controversial regarding postnatal growth of posterior cranial base. Zuckerman (1955) found that it grows slowly at first and then quickly during adolescence. Ford (1958) said that it continues to grow during adolescence while Hoyte (1975) stated that longitudinal growth of posterior cranial base ceases early in the second decade but the synchondrosis between the postsphenoid and basiocciput persists until 25 years.

King (1952) observed that the most superior fibers of the intrinsic pharyngeal musculature run between the pharyngeal tubercle on the inferior surface of the basilar part of the occipital bone and the posterior margin of the medial pterygoid lamina of the sphenoid bone. He concluded that any increase in the dimension between these two, i.e. growth at the speno-occipital synchondrosis, will lead to increase in antero-posterior dimension of nasopharynx.

This view is also shared by Todd and Tracy (1930), Scott (1935), and Ricketts (1954).

Given that the cranial base angle does not affect nasopharyngeal depth, there is a controversy on the degree of flexion. Bjork (1955) reported gradual increase in flexion of cranial base up to 10 years only, while Zuckerman (1955) noted a sudden increase during adolescence, and Ford (1958) denied any true postnatal increase.

Rosenberger (1934) indicated that an enlargement of the naso-respiratory area was achieved by growth in the body and the great wing of the sphenoid as well as by a forward drift of the hard palate.

Keith and Campion (1922) stated that growth at spheno-occipital junction would carry a forward migration of the pterygoid processes, hence giving pharyngeal space for breathing and swallowing.

This view, however, was later refuted by Takagi (1962) who showed that during the first two decades the vomer moves posteriorly, progressively covering the inferior surface of the postsphenoid; and further disputed by Bergland (1963) who reported that these changes in the vomer together with a similar posterior movement of the medial pterygoid plates cause the posterior nasal apertures to become more posterior in position and more vertical.

A number of earlier authors, on the other hand, observed a constancy of the antero-posterior diameter of the nasopharynx (Piersol 1936; Lederer 1947). Bergland (1963) was able to explain this because of the appositional growth in a posterior direction of the choanal structures, thus using up the available space produced by growth of cranial base.

King (1952) nevertheless contended that either a forward migration of the face, a backward movement of the occipital bone, or both do occur, and commented on an increase in the total depth of nasopharynx in the first or second year of life.

It is interesting to note that McCarthy (1925) suggested that variation in the size and prominence of the atlas tuberosity would

have some influence on the size of the nasopharyngeal airway, and King (1952) illustrated a forward growth of the atlas in minimising increase of nasopharyngeal depth.

To sum up, it is apparent that any flexion or growth of cranial base is compensated for by contrary movements of vomer and atlas.

2.4.1.2 Height

The increase in postnatal height of nasopharynx is natural. While Negus (1940) described vertical development as the larynx migrating away from the nostrils, King (1952) attributed such phenomenon as resulting from the descent of the hard palate, the mandible, and the hyoid bone as well as from an increase in the height of the cervical vertebrae.

Subtelny (1957) also demonstrated vertical growth of the nasopharynx and observed a steady rate of increase until 15 years of age.

Similarly, Bergland (1963) disclosed a 38 per cent increase in nasopharyngeal height from 6 years of age to maturity.

2.4.1.3 Width

The postulation by Hellman (1927) of a stabilization of post-natal nasopharyngeal width at an early age was later confirmed by Subtelny (1955) who used frontal cephalometric laminagraphs of infants up to the age of 3 years, and showed a leveling off of bihamular width near the end of the second year.

In contrast, Bergland (1963) noted an increase in choanal width after 6 years of age and an adolescent acceleration too. He ascribed it as due to an increase in the vertical height of the divergent medial pterygoid plates, and possibly to remodelling of these bones. Width increase was also observed to be less than that of the height increase.

2.4.1.4 Capacity

Although the shape of the skull is said to be established by the age

of 3 months (Brodie 1941), there is a disproportionate increase of visceral cranium over the neurocranium (Frazer 1946).

Bergland (1963), in a study using skulls from 6 years to adulthood, observed an actual narrowing of the roof of nasopharynx, despite flexion of the cranial base. The volume of the bony nasopharynx, however, increased from 5.8 c.c. to 10.5 c.c. during the same period, i.e., an increase of about 80 per cent. He imputed this to changes in height and width, while depth remains stable.

The nasopharynx is understandably looked upon as a region of adjustment between early developing neurocranium and the late developing visceral cranium (Griffin and McGrath 1978).

2.4.2 Soft Tissue Elements

Keeping in mind Schuller's (1929) remark of the importance of the configuration of surrounding bone structures in determining the shape and size of the nasopharyngeal cavity, it is conceivable that as the bony confinement assumes new form due to growth, the soft tissue housing attached would alter accordingly.

While demonstrating a steady rate of increase of vertical growth of nasopharynx till 15 years of age, Subtelny (1957) also reported an increase of nasopharyngeal depth at the level of the palatal plane, contrary to the accepted constant nature of bony nasopharyngeal depth.

It was abscribed as due to the posterior wall of the nasopharynx not vertically suspended from the base of the cranium, but curves downward and backward until it assumes a more vertical relationship after passing a point somewhat below the nasopharyngeal level. Therefore the descent of the palate would seem to increase the antero-posterior depth of the nasopharynx.

The increase in vertical dimension of the soft tissue nasopharynx has been looked upon by Ardran and Kemp (1972) in three chronological stages:

- (1) At birth, the mouth is situated at a much higher level relative to the cervical spine and the posterior pharyngeal wall is

situated further forward than in the adult, but proportionately the pharyngeal cavities are similar between the two. Velopharyngeal closure can easily be effected in the newborn by lifting of the soft palate against the skull base, aided by the tongue.

- (2) In the infant, with rapid descent of the palate and the face, the line of the hard palate reaches the level of the atlas at 4 - 6 years of age. During this period, adequate closure of nasopharynx is maintained by elevation of soft palate to the sudden growth of adenoid tissue, since reaching the skull base becomes impossible.
- (3) In the adult, if adult proportions have been reached, the soft palate can appose easily to the pharyngeal wall, aided by contraction of the nasopharyngeal sphincter.

After investigating 30 normal subjects, Subtelny (1957) reported that average growth in length of the soft palate is most rapid during the early years of life and levels off around 2 years old, then resumes its upward trend after 4 - 5 years old. An increase in acuteness of the angle between soft and hard palates with age is also observed.

The growth of adenoids can somehow be viewed as 'space fillers' useful only during the infantile period of disproportionate pharyngeal growth, and the rate of adenoid growth hence very much dependent on the rate of upper face growth (Ardran and Kemp 1972).

On the contrary, Subtelny (1956) visualized the initial rapid growth of adenoids during the early years as a factor causing a concomitant descent of the upper face to permit airway maintenance.

While most researchers are convinced of a definite growth cycle associated with adenoids, few share the same conjecture regarding its chronology or etiology.

Handelman and Pruzansky (1967) contrived that adenoids judged large relative to their nasopharyngeal housing are most frequently observed between 4 and 6 years of age and become less often seen in older groups.

After studying 140 children from age 3 months to 15 years, Johannesson (1968) recounted an increase of adenoids during the first two years of life but remained unchanged afterwards. Eller, Roberts and Ziter (1971) on the other hand held that involution of nasopharyngeal adenoids is not complete by age 25 years but continues throughout life.

While Capitanio and Kirkpatrick (1970) expressed concern that in children over 6 months of age, absence of adenoids is significant and imply an immune deficiency, they were unable to find soft tissue mass in nasopharynx of infants less than 1 month of age.

Ardran and Kemp (1972), however, observed that the adenoids are absent at birth, start growing at 6 months, reach the largest size at 5 - 7 years of age, persist for some years and then regress. They also recorded presence of adenoids in adults with small tongues.

Devgan and Leach (1979) noticed that at birth the adenoids are very small but are present nonetheless, and grow to be largest at 3 years, thereafter slowly regressing and involuting until 5 to 6 years of age, finally disappearing by puberty. Showing this in Fig. 11, they also asserted pathological conditions if there is persistence of adenoids beyond puberty.

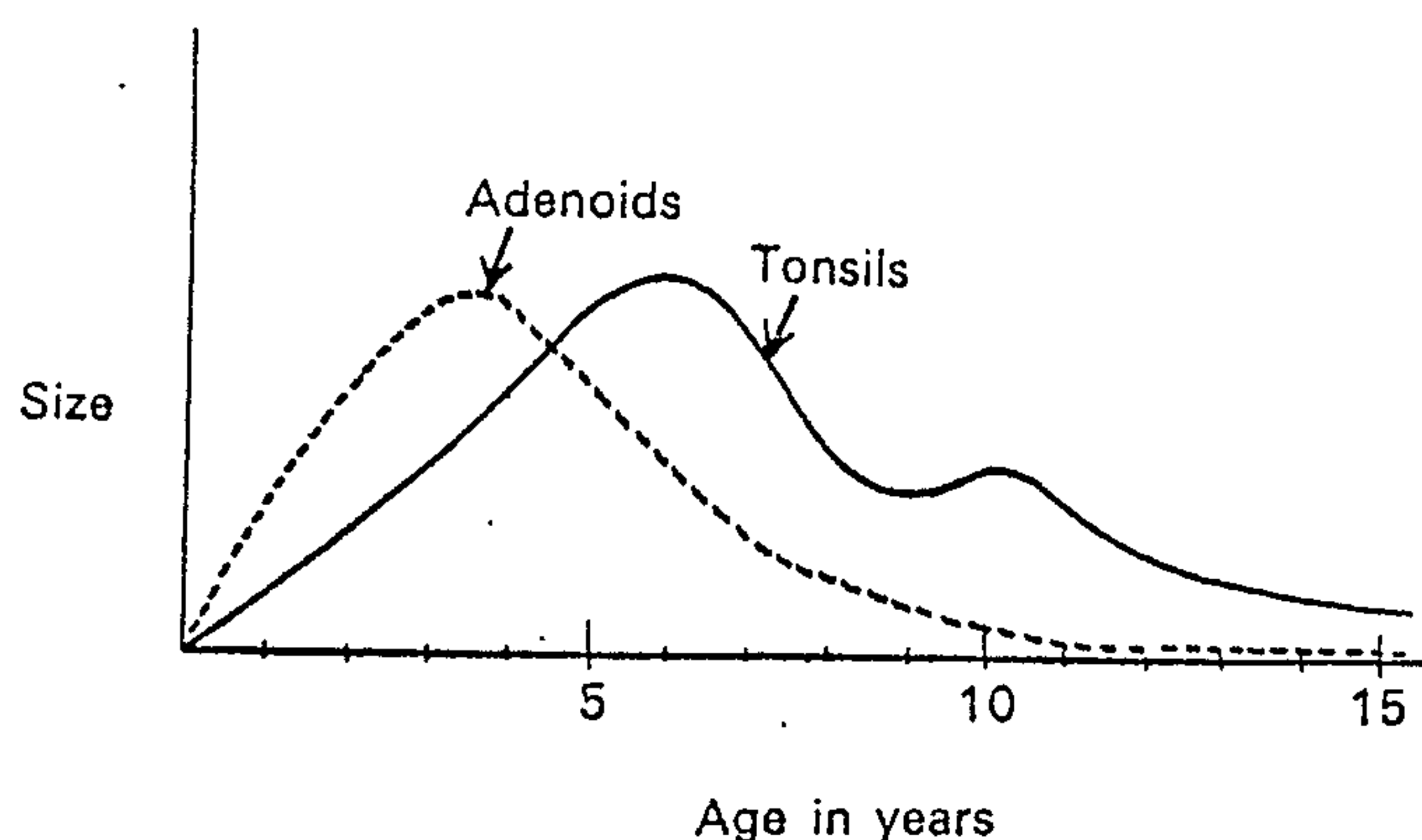


Fig. 11. The adenoid growth curve
(From Devgan and Leach 1979)

In an earlier study by Subtelny (1956), adenoids are evident on radiographs by 6 months to 1 year of age, and rapid growth ensues reaching a peak level between 10 to 15 years of age. Atrophy is

believed to follow until adulthood when the nasopharynx reaches its maximum dimension.

An assessment of this pattern was provided by Scammon (1930) who showed a peak growth of lymphatic tissues at about 10 to 11 years of age. Adenoids being lymphatic, may well follow this same path of growth (Subtelny 1956).

In contrast, Pruzansky (1975) questioned the wisdom of applying the Scammon's growth curve in this context. The original Scammon data did not include measurements of adenoids and tonsils which possess disparate embryonic origins and cytology to the rest of Waldeyer's ring anyway. He therefore rejected the idea of a true growth curve, but adenoids and tonsils respond only to the stress and immunocompetence experienced by each individual.

A similar view is shared by Sperber (1976).

It is of interest also to note that Henrikson, Linder-Aronson and Westborg (1975) studied 113 children aged 6 to 15 years cephalometrically and found a significant change in antero-posterior dimension of nasopharynx during a six-month period only in pre-pubertal children.

2.5 CONCLUSION

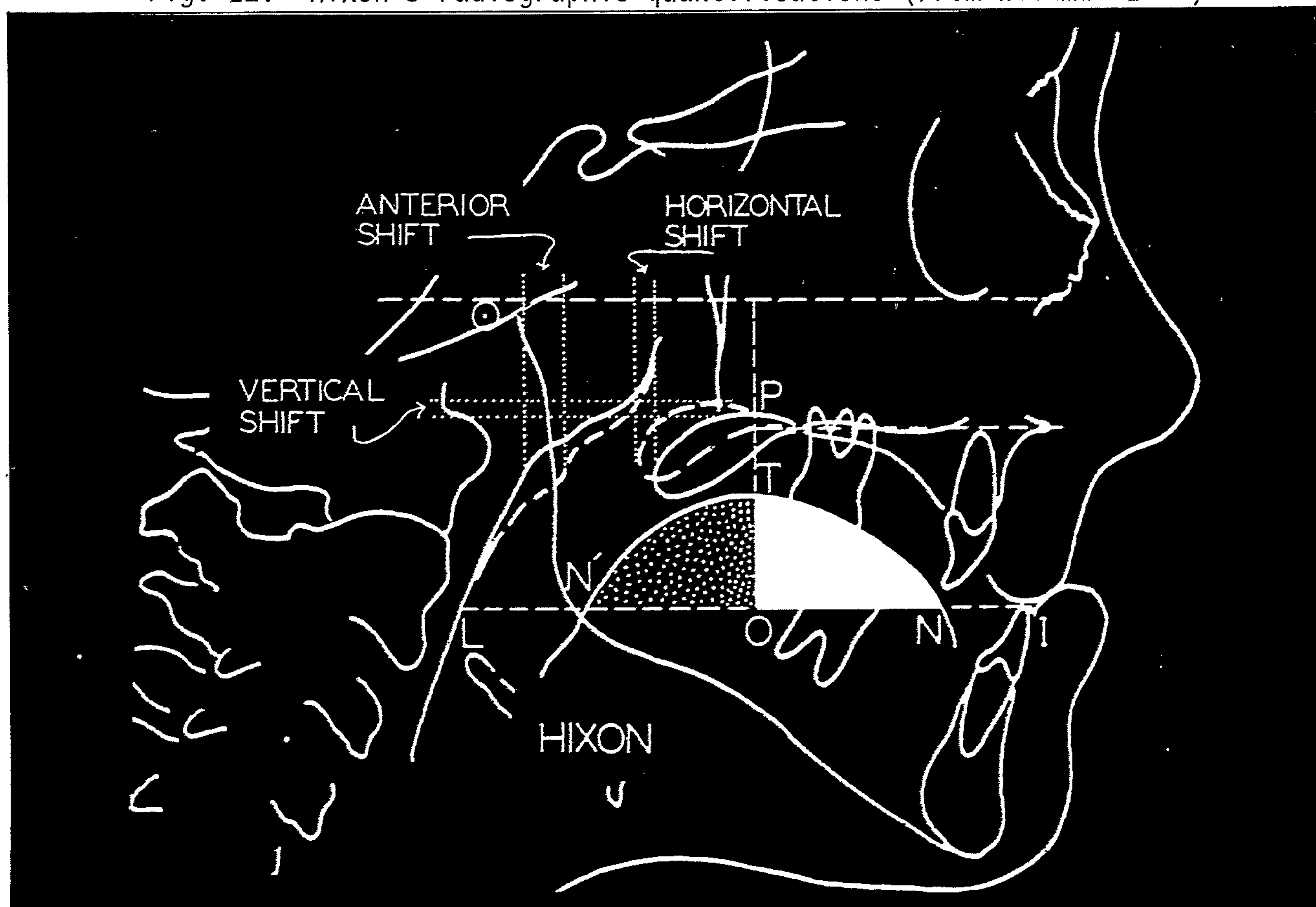
By definition, bony nasopharynx is bound by basisphenoid, basiocciput, condylar portion of occipital bone, anterior point of atlas, vomer, and medial pterygoid plates. Within this framework is the soft tissue elements of nasopharynx comprising of lateral, posterior and superior walls with associated lymphatic tissues, and a mobile soft palate.

In normal nasopharyngeal development, a fine state of equilibrium is established whereby elements of both bony and soft tissue nasopharynx adjust to the differential growth of neuro- and visceral cranium, in order to maintain adequate respiratory function.

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Fig. 12. Hixon's radiographic quantifications (From Wildman 1961)



CHAPTER 3: METHODS OF EXAMINING THE NASOPHARYNX

3.1 NON-RADIOGRAPHIC

The inaccessibility and the dynamic nature of the nasopharynx make it one of the hardest body parts to be physically examined.

Knowing the importance of accurate evaluation of the adenoids in children with naso-sino-nasopharyngeal problems, Goldman and Bachman (1958) also appreciated the difficulties involved often resulted in an unsatisfactory examination.

Several methods are available singly or in combination to evaluate adenoidal tissue and to examine the nasopharynx. It is out of the scope of this study to discuss such procedures in detail. They may nevertheless be briefly mentioned.

- (1) Indirect visualization with mirrors (Johnson, Green and Rise 1967; Devgan and Leach 1979).
- (2) Digital examination or palpation. This method is traumatic physically and psychologically, and there is a danger that the child may subsequently be wary of his examiner and refuse further treatment (Gay and Breslaw 1960; Johnson, Green and Rise 1967; Devgan and Leach 1979).
- (3) Palpation through the soft palate is indeed less traumatic but inaccurate (Gay and Breslaw 1960).
- (4) Posterior and anterior rhinoscopy. In the hands of the skilled, posterior rhinoscopy using a post-nasal mirror will often yield good information, but it demands cooperation from a very young person (Gay and Breslaw; Johnson, Green and Rise 1967).
- (5) Nasopharyngoscopy using electric nasopharyngoscope. This is a good method, especially for checking pathology in the neighborhood of the Eustachian orifice, but not every child will tolerate this instrumentation (Gay and Breslaw 1960; Devgan and Leach 1979).
- (6) Whereas flexible fibre-optic endoscopes can be used for examination and obtaining target biopsy of the gastro-intestinal tract, rigid fibre-optic endoscopes have recently been applied to naso-endoscopy (Salmon 1974; Schiller and Salmon 1976).

- (7) The use of a palatal window to allow for easy inspection is done only in occasions where serious pathology is suspected (Rubin 1972).
- (8) A soft rubber catheter can be passed through the nose into the mouth and may offer superior palatal retraction (Rubin 1972).
- (9) Examination of the nasopharynx under topical anesthesia and a small mirror (Rubin 1972) or under general anesthesia as a step prior to surgical intervention (Gay and Breslaw 1960).
- (10) Clinical features of chronic adenoiditis, EKG, audiometry, tympanometry, and weight of surgically removed tissues are also helpful (Devgan and Leach 1979).
- (11) Real time ultrasonic multi-transducer two dimensional cardiac B-scanning equipment has also been used to visualize pharyngeal walls extending from nasal to oral pharynx (Skolnick, Zagzebski and Watkin 1975).

Rhinoscopy, mirror examination and digital palpation have been doubted seriously by Weitz (1946), Goldman and Bachman (1958), and Devgan and Leach (1979) because of the impracticality, trauma, and the highly subjective nature inherent in these methods.

3.2 RADIOGRAPHIC

Adenoidal vegetations were pointed out on the roentgen film as early as 1898 by Mignon followed by Scheier (1904) during a demonstration of the epipharynx using radiographs. It was not until two decades later when Grandy (1925) gave a roentgenographic depiction of adenoids, and Groth (1933) submitted a comprehensive paper on the roentgen aspects of the epipharynx and adenoids.

3.2.1 Plain Radiography

The use of plain radiographs to examine nasopharyngeal conditions has been widely approved, notably Weitz (1946) when he considered that a single lateral radiograph of the pharyngeal area is suffice to give anatomical and pathological information.

This technique was similarly advocated by Zwiefach (1954) who

stressed the importance of proper interpretation, by Goldman and Bachman (1954) who saw the advantage of minimal roentgen exposure, and by Gay and Breslaw (1960) who regarded the procedure as simple, applicable to all cases, no instrumentation necessary, and no great skill involved other than accurate reading of the radiograph.

Pruzansky (1966) was able to account for the presence of transitory upper respiratory tract infections with concurrent increase in adenoid sizes observed on serial cephalometric radiographs. Khoo, Tye, Chia and Ng (1977) even devised a system of measurements on a single lateral radiograph of subjects suspected of nasopharyngeal carcinoma giving results as accurate as 85 per cent.

A standardised and reproducible method to take a lateral radiograph is clearly essential. The most accepted approach is to place the subject in an erect position, with dentition in occlusion or jaws at rest, absence of deglutition or phonation, and respiration suspended during nasal inspiration (Goldman and Bachman 1954).

Sometimes, more than one plain radiograph is used. Bloch and Quantrill (1968) recommended an additional submento-vertical view of the skull, but opposed the use of frontal radiographs because of superimposition of overlying structures.

According to Ho (1972), the following views are required in a routine differential diagnosis of nasopharyngeal lesions:

- (1) Lateral;
- (2) Submento-vertical (axial);
- (3) Occipito-submental;
- (4) 25 degrees occipito-mental, and
- (5) Occipitomaxillary (25 degrees occipitofrontal).

3.2.2 Tomography

Tomographic techniques in the profile view of the nasopharynx has been in use, to a limited extent, since Bayer (1939). Lateral tomography through the midline of the skull was recommended by Block and Quantrill (1968) to show a soft-tissue mass indenting the pharyngeal shadow, erosions of skull base and other pathology.

Goldman and Bachman (1958), on the contrary, do not find this method to yield additional information.

A modified form of tomography, called autotomography had been developed by Plantes (1950) to eliminate the super-imposition of two different air-containing systems and define one of them clearly. It was adopted by Schvarcs (1959) to demonstrate naso- and oropharynx by rotating the subject's head from side to side to blur out the overlying mastoid air cells.

To refine this process even further, Lame and Redick (1969) constructed a clear plexiglass wand upon which the subject's head can be smoothly rotated so that a lateral autotomogram can be easily done giving valuable information.

With the invention of computed tomography (Housfield 1973), regional anatomy of nasopharynx is now more explicit (Alfidi, Haaga, Weinstein and DeGroot 1977), and its use in examining lesions in nasopharynx has been proven (Wortzman and Holgate 1976).

By conducting serial transverse scans of the head, Alfidi et al (1977) compared the anatomy of nasopharynx with respective cuts from preserved cadavers, and found a distinct manifestation of details on computed tomograms. Figs. 12 - 19 show four pairs of such serial sections at 0 degrees to radiographic base line (i.e., orbital-meatal line).

3.2.3 Contrast Radiography

Contrast radiography is defined by Ho (1972) as a procedure whereby an opaque medium is used to coat the mucosal surface or fill the nasopharyngeal lumen, and in both cases the patient is subjected to a certain amount of discomfort while intelligent cooperation is essential.

Zuppinger (1931), Groth (1933), and Ruedi and Zuppinger (1934) were probably some of the earliest investigators to report on contrast radiography applied to the nasopharynx.

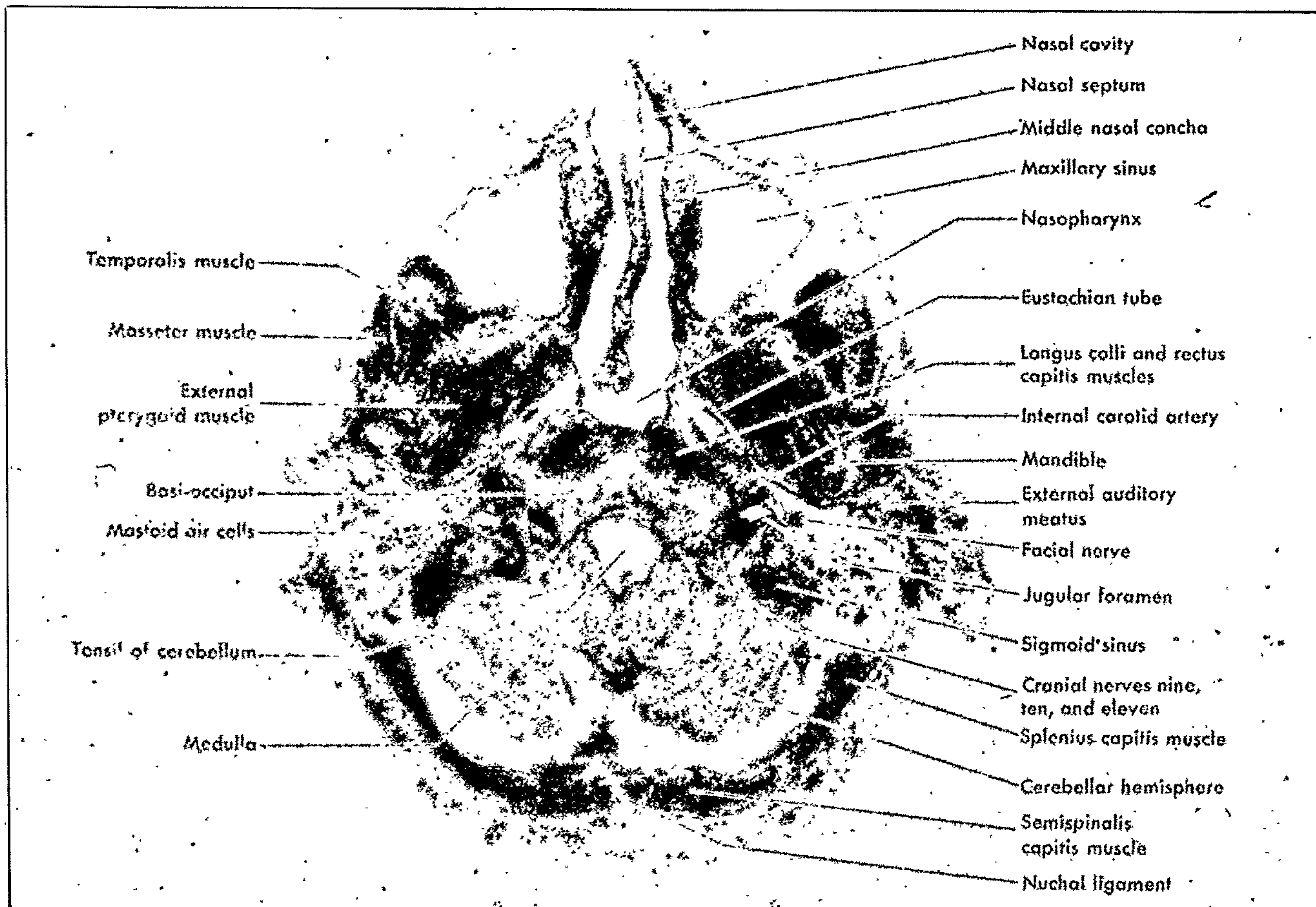


Fig. 13. Cadaver head section at orbitomeatal level and 0 degree to orbitomeatal line (From Alfidi et al 1977, p. 78)

Fig. 14. CT slice of 8 mm thick corresponding to section in Fig. 13 (From Alfidi et al 1977, p. 79)



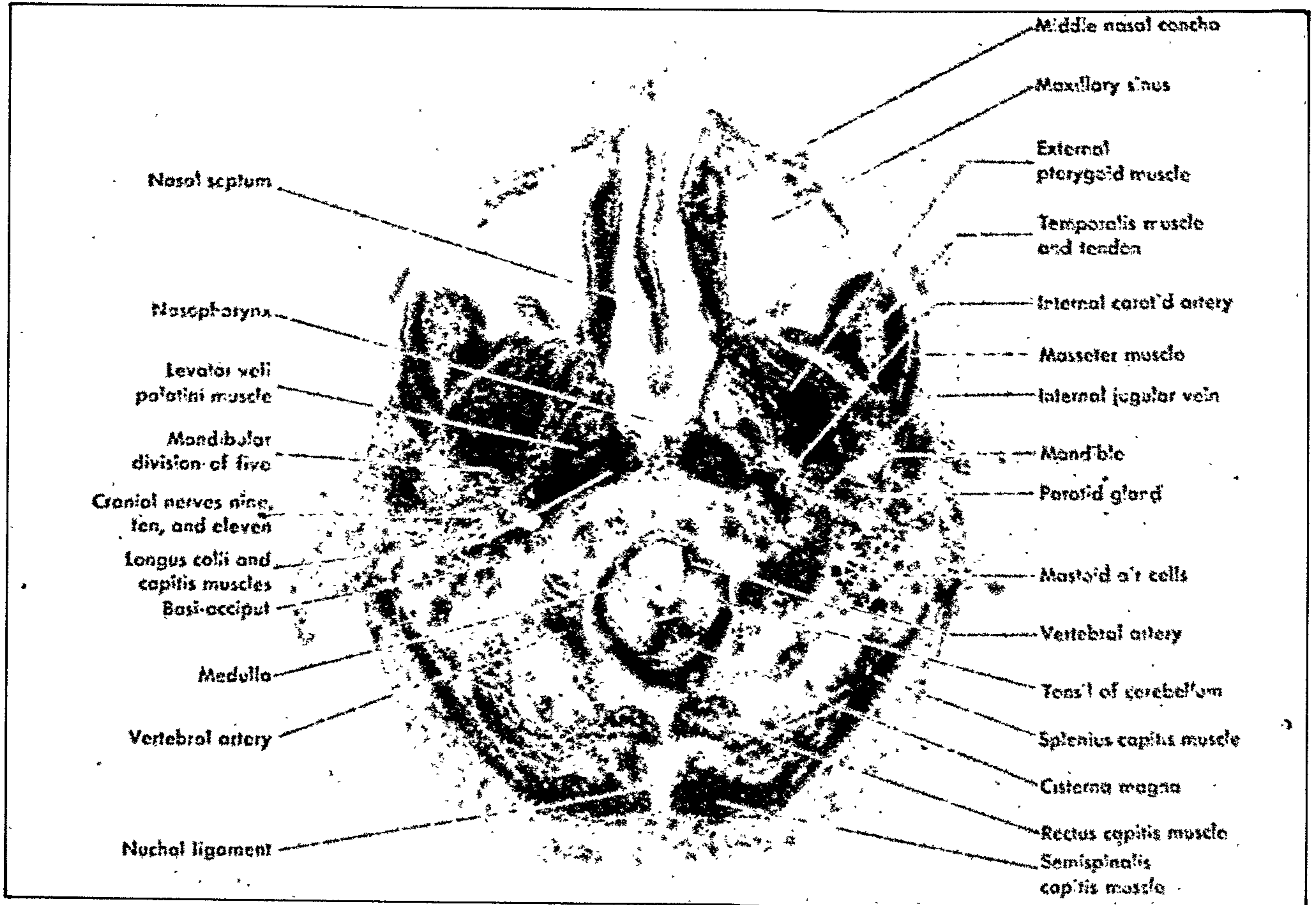
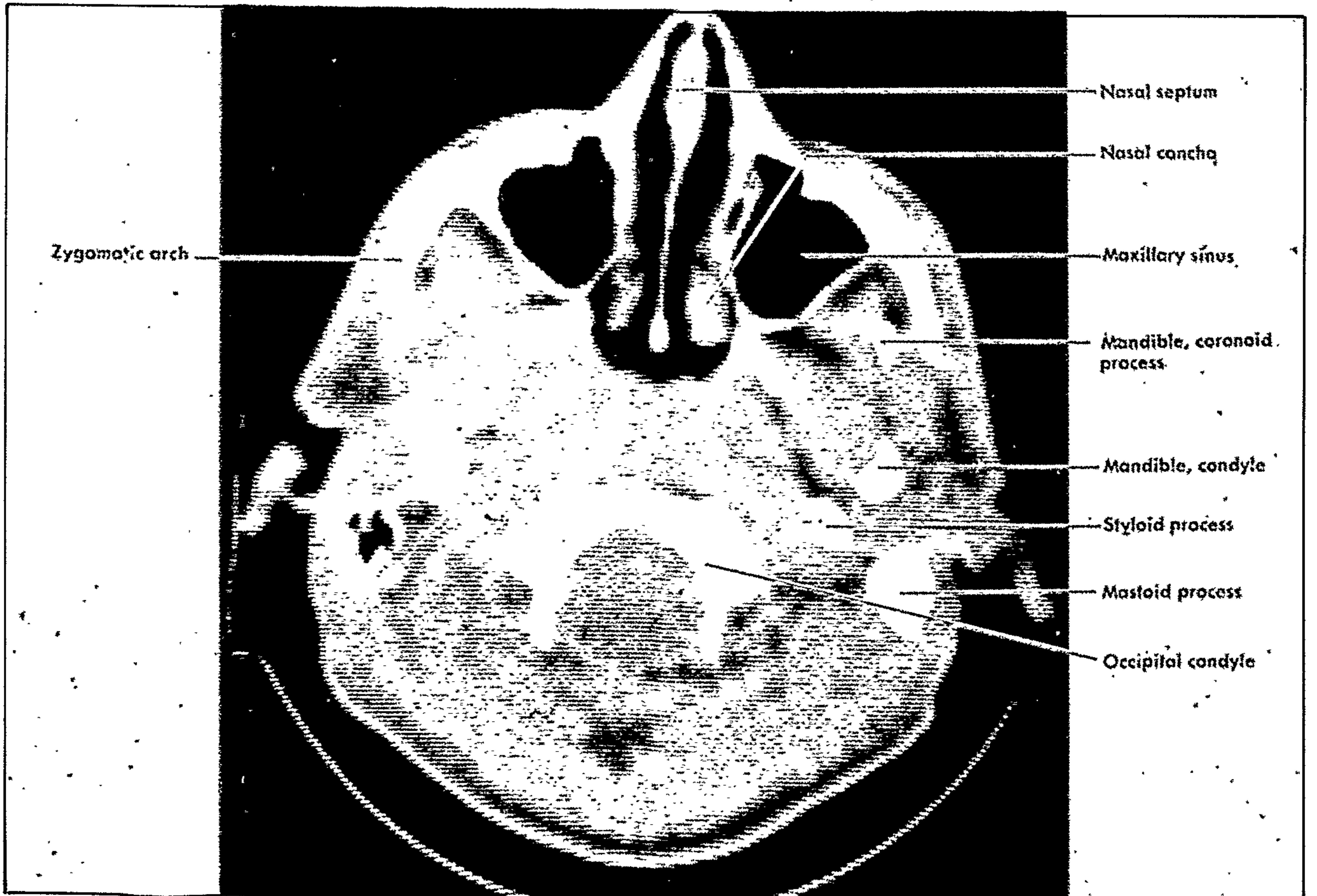


Fig. 15. Cadaver head section 8 mm below that of Fig. 13 (From Alfidi et al 1977, p. 80)

Fig. 16. CT slice corresponding to Fig. 15 (From Alfidi et al 1977, p. 81)



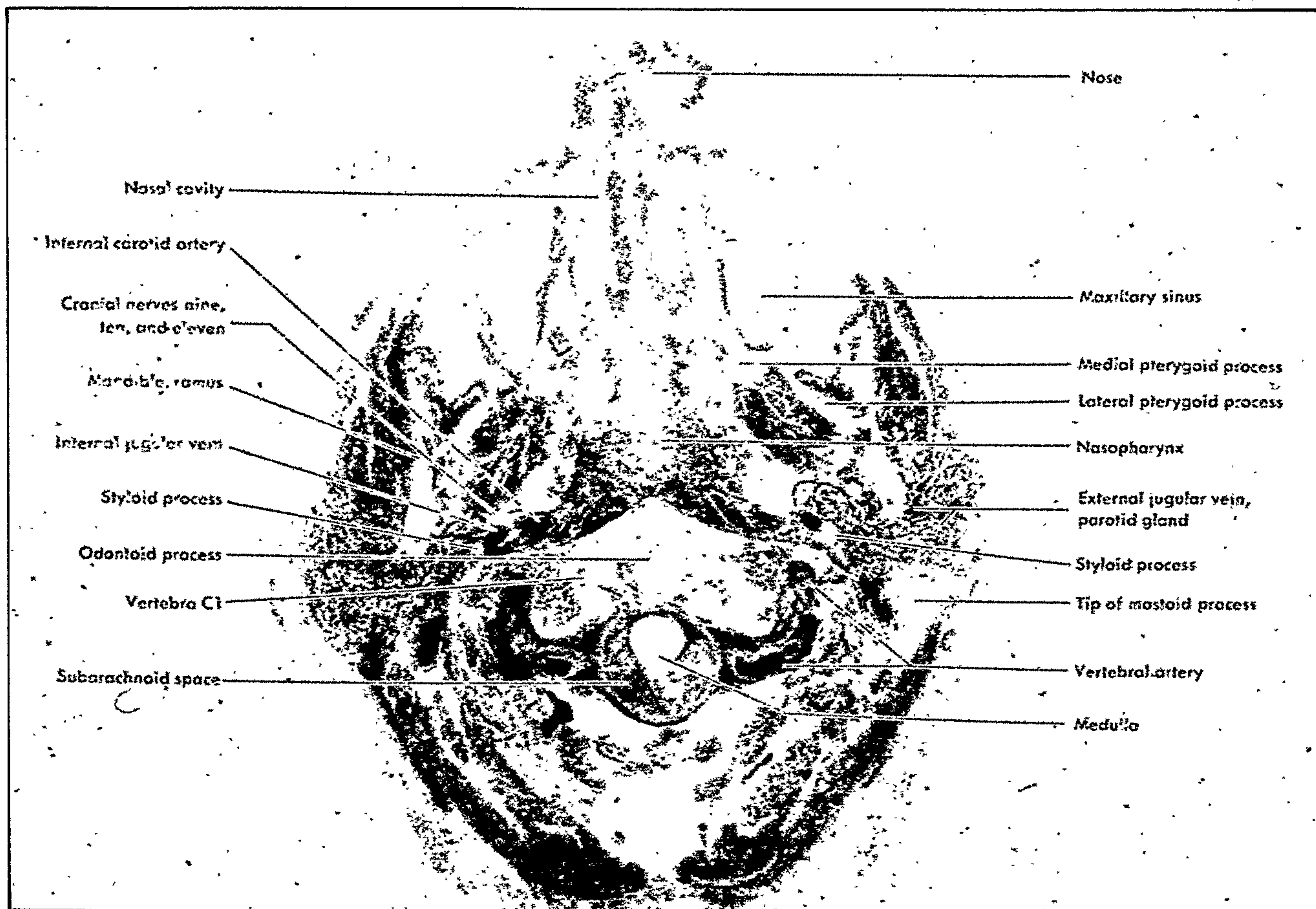
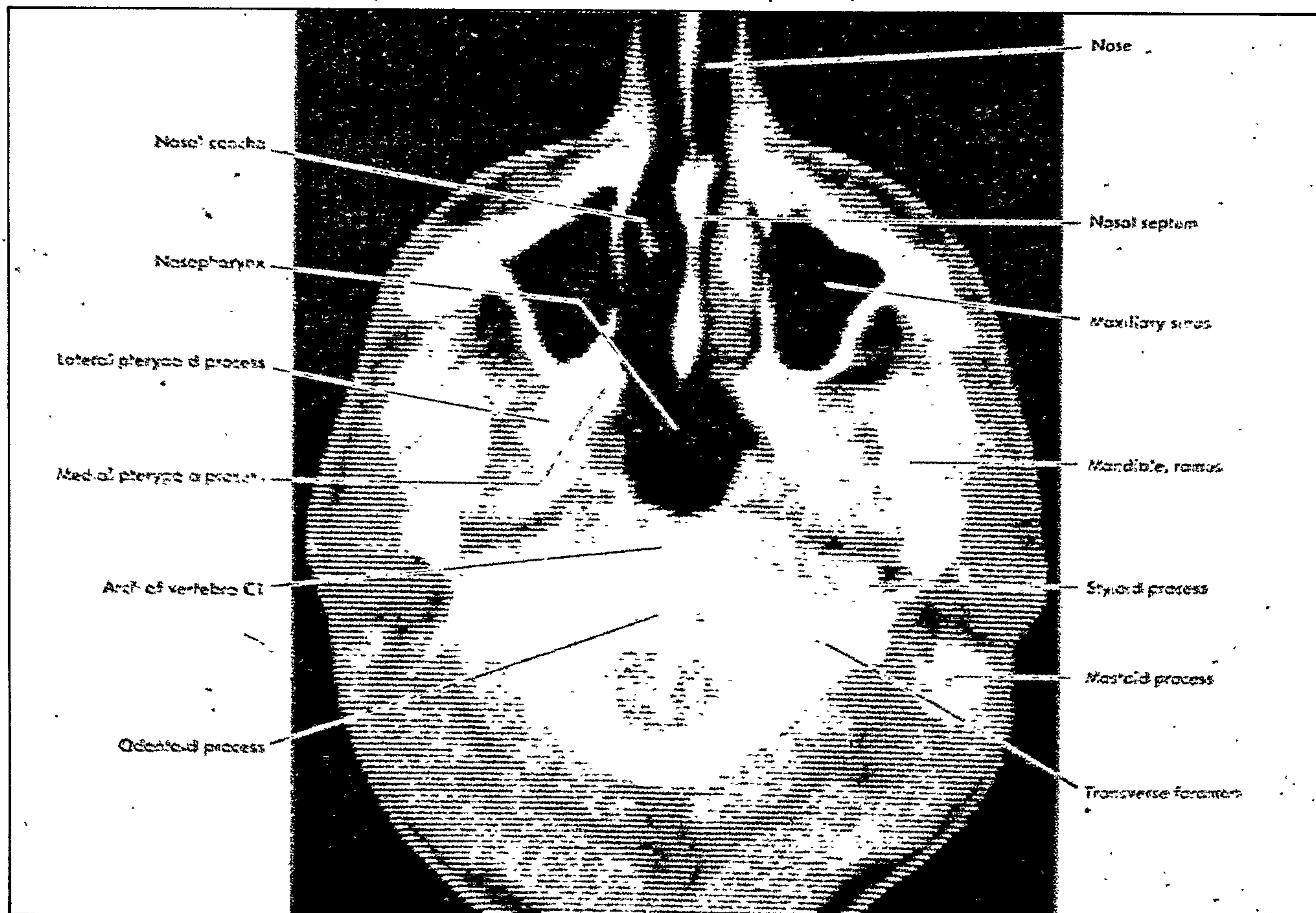


Fig. 17. Cadaver head section 8 mm below that of Fig. 15
(From Alfidi et al 1977, p. 82)

Fig. 18. CT slice corresponding to Fig. 17
(From Alfidi et al 1977, p. 83)



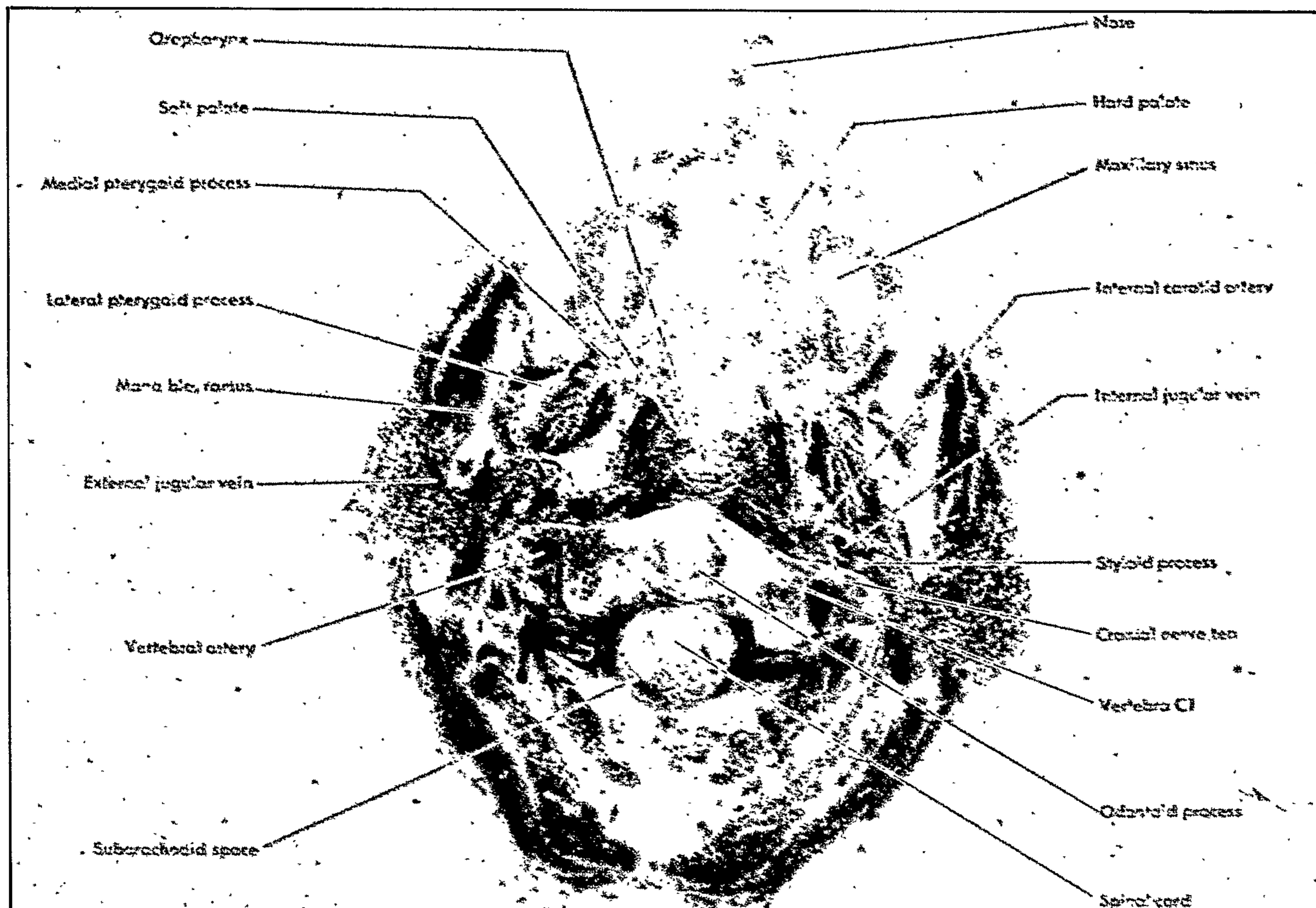
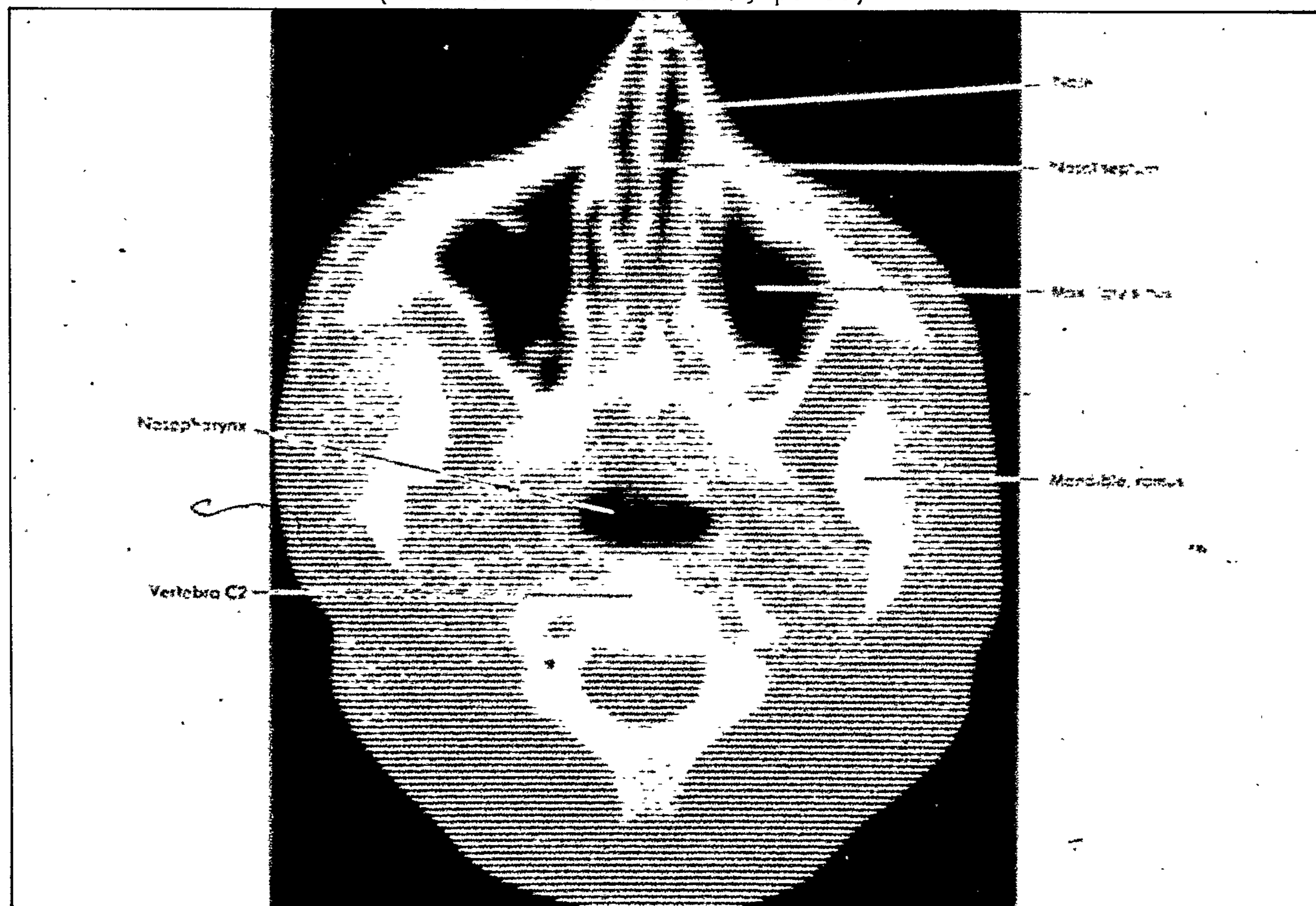


Fig. 19. Cadaver head section 8 mm below that of Fig. 17
(From Alfidi et al 1977, p. 84)

Fig. 20. CT slice corresponding to Fig. 19
(From Alfidi et al 1977, p. 85)



At first, 'lipiodol' was used (Khoo, Chia and Nalpon 1967), followed by barium (Khoo, Kanagrasuntheram and Chia 1967), and then 1.25 to 1.5 per cent solution of carboxymethylcellulose and Micropaque (Johnson Jr., Green Jr., and Rise 1967).

Contrast radiography in the lateral and submento-vertical projections have been used by Suchato, Tuchinda and Palavatana (1973) to study the nasopharynx of patients suffering from nasopharyngeal carcinomas pre- and post-irradiation, and by Bloch and Quantrill (1968) to detect tumours.

The indications to perform contrast radiography on nasopharynx, as advanced by many researchers, but summarised by Evison (1968) are:

- (1) When a nasopharyngeal growth has been detected clinically, or on a plain film, and it is desired -
 - (a) to see the extent and size of the growth,
 - (b) to see if the Eustachian tubes are affected.
- (2) Where a nasopharyngeal newgrowth is suspected clinically, though plain films and endoscopy have failed to locate it.
- (3) Any case of malignant enlargement of cervical nodes where a primary locus is being sought.
- (4) To show the response of nasopharyngeal neoplastic masses to treatment, e.g., radiotherapy or surgery.
- (5) To demonstrate the patency of the Eustachian tubes prior to operations such as tympanoplasty.
- (6) Occasionally, to show other lesions which may not be fully visible on endoscopy, e.g., hypertrophied posterior turbinates, choanal polypi, or choanal atresia.

In addition to the afore-mentioned lateral and submento-vertical projections, Khoo, Chia and Nalpon (1967) developed methods to produce contrast radiographs of the nasopharynx in the frontal, right and left anterior oblique projections as well.

Allowing for minor variations, the procedure of obtaining contrast radiographs of the nasopharynx involves:

- (1) Topical anesthesia of the nasal passages, oropharynx and fauces by nasal drops and sprays.
- (2) The patient is instructed to breathe through the mouth with the

- head placed at a pre-determined position.
- (3) About 10 - 15 c.c. of contrast agent is introduced into each nostril via a rubber catheter.
 - (4) Fractional instillation with films at each level or air-contrast films can be prescribed.
 - (5) Different radiographic projections are then obtained.
 - (6) The patient is then allowed to sit up the expel the medium.
 - (7) Air-contrast outlines of the nasopharynx can be obtained following clearance of medium.

Examination of the soft palate, as suggested by Ardran, Kemp and Wegelius (1957) and adopted by Bloch and Quantrell (1968), can be furnished by taking a palatogram after introducing barium cream through the nostril and the mouth with swallowing. The upper surface of the soft palate and the posterior wall of the nasopharynx are hence effectively coated.

Khoo, Chia and Nalpon (1967) related three conditions necessary to give good contrast nasopharyngography:

- (1) The procedure must be relatively innocuous and capable of being tolerated by the patient.
- (2) Availability of a suitable contrast medium providing good contrast as well as good mucosal adhesive property and barium column cohesive power.
- (3) Radiographic equipment capable of providing convenient fluoroscopy, roentgenography and cinefluorography.

Although patient tolerance and discomfort are obvious deterrents to apply contrast nasopharyngography widely, Evison (1968) considered it possible to obtain satisfactory radiographs provided that the process is explained to the patient before hand.

Suchato, Tuchinda and Palavatana (1973) reported a complication in contrast nasopharyngography involving the filling of the paranasal sinuses especially the ethmoid sinuses, though patient complaint is rare.

The use of contrast nasopharyngography was abandoned by Zwiefach (1954) because he found that a normal soft tissue film is as reliable. Ho

(1972) equally doubts the necessity of using a contrast medium since air itself is a highly satisfactory natural contrast medium, and it depicts the soft tissue outlines without obscuring the neighboring bones. He also sees an added advantage of air, being a gas, diffuses into narrow spaces such as the lateral pharyngeal recesses better than any viscous fluid can.

3.2.4 Contrast Cinefluorography

The application of contrast cinefluorography on the nasopharynx was first reported by Khoo, Chia and Nalpon (1967) though cineradiology of the pharyngeal region has been developed and used for a long time (Roberts 1957; Nicholas, Bays and Lyon 1975).

It is not intended here to propound the details of cinefluorography but it is interesting to note that Khoo, Chia and Nalpon (1967), in a comprehensive examination of the nasopharynx using frontal and oblique projections with the aid of image intensification fluoroscopy, concluded that this method provides not only a study of the radiographic anatomy, but also of the dynamics of the region.

The investigation shows several unexpected features:

- (1) Barium initially collects as a relatively narrow central tubular column within the nasopharynx and subsequently fills the pharyngeal recesses. The central 'functional' channel is about half the width of total nasopharyngeal width.
- (2) Many variations in size and shape.
- (3) A high degree of expansion and contraction of the lateral walls of the nasopharynx during deglutition, thus indicating a great degree of pliability of these walls.

At variance with the above authors, Ho (1972) considered it unnecessary to employ cinefluorography because only the floor of the nasopharynx, which is formed by the soft palate and which presents the least problem in diagnosis, is mobile.

The value of contrast cinefluorography of the nasopharynx therefore depends on the nature of the problem, and is best used when the dynamics of the region need to be assessed.

3.2.5 Xeroradiography

Although claims for superiority of xeroradiographs have been substantiated (Erskine 1978), and that xerocephalography gives a better soft-tissue analysis than conventional cephalometric radiographs (Schrivver, Swintak and Darlak 1975), specific advantage of applying this technique to examine nasopharynx has not been proven.

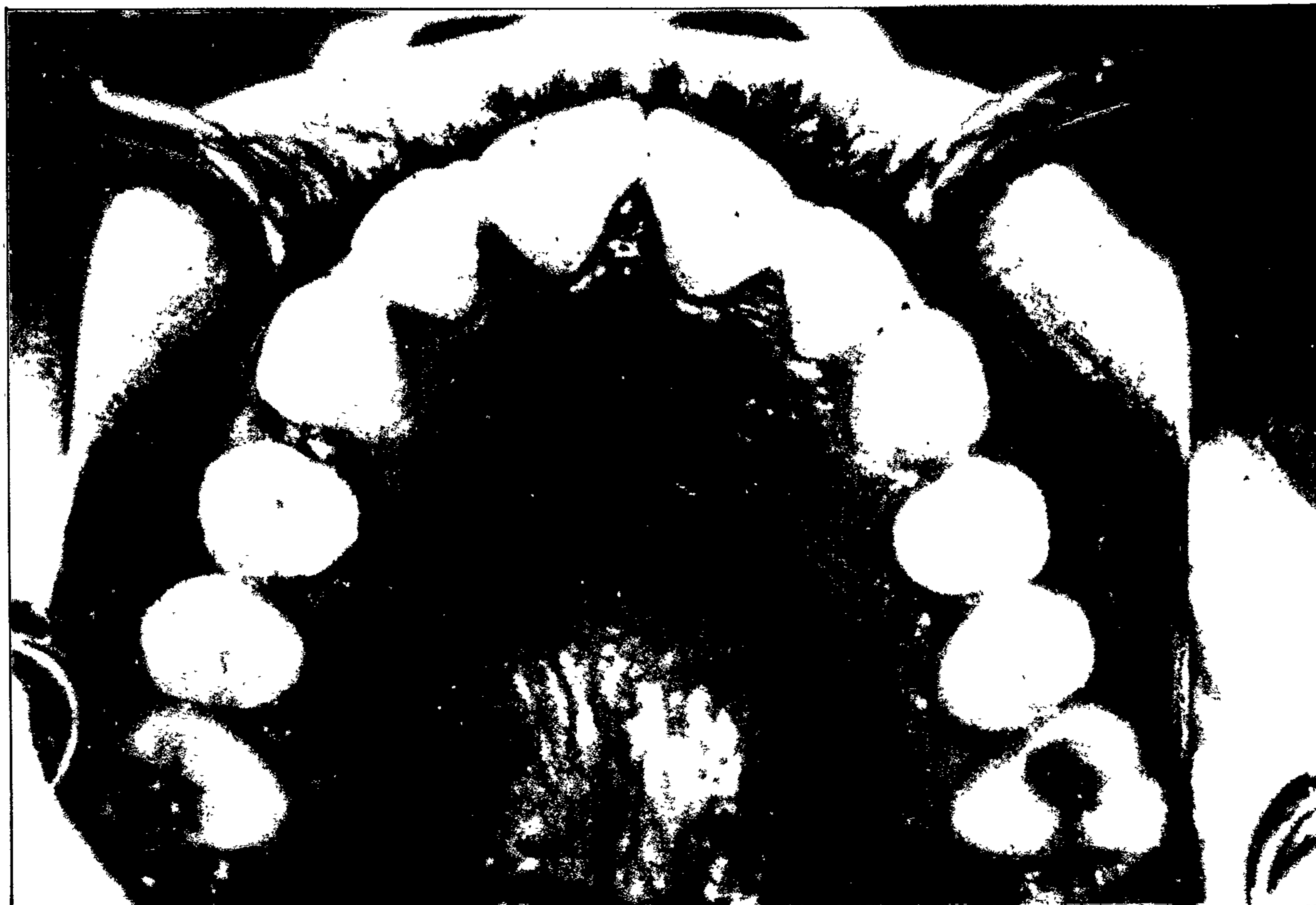
3.3 CONCLUSION

- (1) Radiographic examination of the nasopharynx is accurate, simple and safe, having regard to radiation dosage levels, though it is utilised less frequently than it deserves (Goldman and Bachman 1958).
- (2) Accurate interpretation of the radiograph is essential, and limitations to each method must be understood.
- (3) Plain radiographs are adequate for routine examinations while sophisticated methods are useful to investigate the extent and nature of suspected serious lesions, or to appreciate the dynamic nature of the region.
- (4) Radiographic methods are not designed to replace direct methods. Both give information, but findings of one method supplement and confirm those of the other (Johnson Jr., Green Jr., and Rise 1967).

CHAPTER 4: RADIOGRAPHIC QUANTIFICATIONS OF NASOPHARYNGEAL
DIMENSIONS

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Fig. 21. View of maxilla, intra-oral, subject 11 .



CHAPTER 4: RADIOGRAPHIC QUANTIFICATIONS OF NASOPHARYNGEAL DIMENSIONS

4.1 INTRODUCTION

Despite the dynamic nature of the pharynx during phonation and deglutition (Shelton and Bosma 1962), the pharyngeal airway progressively stabilises during postnatal development so that its diameter varies less with phases of respiration (Bosma 1963).

Of the five soft tissue walls of nasopharynx, the soft palate is observed to be the only significantly mobile structure, which courses in an upward and backward direction during velopharyngeal closure (Subtelny and Baker 1966). In a relaxed situation, however, the soft palate is seen to be rather stable in position, and has therefore been used frequently as a parameter of nasopharyngeal quantifications (Dunn, Green and Gunat 1973).

Thurrow (1973) was able to demonstrate that in resting posture, the radiographic airway dimension showed remarkable consistency over a wide range of head positions.

It has therefore been possible to evaluate nasopharyngeal capacities on a radiograph provided that the procedure is standardised, with patient's head erect and the soft palate being pendant (Goldman and Bachman 1958; Pruzansky 1975).

The history of radiographic quantifications of nasopharyngeal dimensions has its genesis in 1910 when Kelly endeavoured to correlate 'insufficiency of the palate' and hypernasality with the size of the nasopharynx and bony development of the palate. Measurements were done on a series of dry skulls then.

While Fujioka, Young and Girdany (1979) stressed the importance of simple, accurate and objective radiographic assessments in this context, and the avoidance of impractical or time-consuming methods, Poole, Engel, Chaconas and Encino (1980) praised the value of lateral cephalometrics. They found it possible to view both soft and hard tissues on lateral cephalometric radiographs, the soft tissues of nasopharynx thereby easily related to bony landmarks of

the face and cranium. They further suggested the use of frontal radiographs to attain a three-dimensional perspective.

Highly subjective as they may be, groups of cephalometric measurements selected by various authors are designed to indicate:

- (1) Size of bony nasopharynx.
- (2) Size of adenoids, expressed as either absolute values or as a percentage of nasopharynx.
- (3) Size of airway, also expressed as absolute values or percentages.

When reviewing the vast selections of subjective, linear, angular, areal and volumetric components of the kaleidoscope of nasopharyngeal quantifications, one should perhaps bear in mind some useful criteria dictating the choice of a reference line involving velopharyngeal studies (Wildman 1961):

- (1) It should be the most stable reference line in relation to the variables to be measured.
- (2) It should be in functional and anatomic relation to the variables under consideration.
- (3) It should introduce as few unnecessary variables as possible.

The following review comprises of some forty methods devised by both medical and dental researchers to quantify either the sizes of adenoids or the magnitude of the nasopharyngeal airway.

Emphasis is placed on identifying the degree of obstructive adenoids in the medical literature, thereby leading to a decision for surgery. Since accurate craniofacial measurements are made available by the cephalostat (Broadbent 1931), one sees the frequent use of angles, planes and areas in dental literature to quantify nasopharyngeal airway, the patency of which is regarded by some specialists to play a vital role in dentofacial morphology.

It must be enunciated, however, that methods to quantify nasopharyngeal dimensions were initially contrived to provide a basis whereby other properties could be deduced. Hence, attempts were made to evaluate adenoid sizes on radiographs and correlate such measurements to incidences of nasal obstruction and adenoidectomies (Fujioka, Young and Girdany 1979).

Similarly, studies of velopharyngeal closure in cleft palate patients (Subtelny 1955), derivation of intra-racial norms (Bergland 1963), assessment of nasopharyngeal growth (Castelli, Ramirez and Nasjleti 1973), identification of pathological states (Khoo et al 1974), and research on etiology of mouth breathing (Schulhof 1979) were made possible relying on consistently chosen radiographic nasopharyngeal measurements.

Accent was placed on the reliability of the selected quantifying methods to estimate other parameters rather than the validity of the methods themselves in representing the actual space measured. This is due to the dynamic nature of the nasopharynx and the lack of suitable equipment in the past.

Indeed, the closest to testing the accuracy of radiographic quantifications was to compare clinically and radiographically evaluated adenoids with those removed at surgery (Hibbert and Whitehouse 1978).

In the succeeding review, quantifying methods are grouped according to similar rationale in a chronological order. While details of each method is essential to better the understanding and enrich the pool of information in this connection, it is felt that the pleasure of reading can be enhanced by separating definitions and formulae from the main text by using *light italic* script. The astute reader can undoubtedly pick out the gems of this chapter leisurely.

4.2 RADIOGRAPHIC ANATOMY

Granting the extensive variation in shape of the nasopharynx (Bloch and Quantrill 1968; Khoo et al 1974), the roof, posterior wall and floor of the nasopharyngeal space are easily recognised on a lateral radiograph (Goldman and Bachman 1958).

Difficulty is often encountered in identifying radiographic blind spots at the roof of the choana and the triangular area between the superolateral margin of the choana and the anterior margin of the torus tubarius (Ho 1972), which are obscured by the nasal septum

and pterygoid plates and not visible in other views.

The anterior boundary of the nasopharynx, i.e., the choanae and vomer, though not discernible on a lateral radiograph, can nevertheless be evaluated by drawing a line from the plane of the posterior margin of the hard palate to the point where the upper anterior margin of the pterygoid plate joined the body of the sphenoid (Goldman and Bachman 1958). Either this line or the posterior margin of the antrum corresponds closely to the posterior edge of the vomer and the position of the choanae.

Though adenoids can be distinctly portrayed as a widened, nodular soft tissue mass attached to the roof of the nasopharynx, projection of the earlobe into the nasopharyngeal airway is a common source of error if the head is not in a true lateral position (Goldman and Bachman 1958).

Differential diagnosis of other soft tissue masses in the nasopharyngeal space is regarded by Goldman and Bachman (1958) as fundamental. They identify choanal polyps as soft tissue circumscribed densities separated from the mucous membrane of the vault by a thin band of nasopharyngeal airway. Likewise, the polyps, fibromas and malignant tumors occupying the nasopharynx usually appear after the age when the adenoids have involuted. Fibromas are often huge, homogeneously dense, round and sharply circumscribed opacities quite different from the ovoid, lobulated masses seen attached to the vault in the younger children.

Rizzuti and Whalen (1972) defined nasopharyngeal anatomy seen in the base view of the skull by relating specimen cross sections of cadaver materials to clinical radiographs. They found that the posterior nasopharyngeal wall was in front of the anterior arch of the atlas, and the lateral walls were medial to the pterygoid processes, with a contour which concaved outward. Attention was also drawn to inferiorly related structures like the oropharynx and piriform sinuses which would superimpose upon the nasopharyngeal air column.

4.3 SUBJECTIVE ASSESSMENTS

As Grandy (1925) noted that the diameter of some nasopharyngeal airways could be reduced as much as a quarter of the natural size, he unknowingly set a precedent to assess the nasopharynx on a subjective basis.

Time and again, adenoids were radiographically classified into grades according to their thickness on some selected reference lines or to the amount of airway occlusion they produced.

Whereas Backlund (1963) grouped adenoid sizes into two grades, Weitz (1946), Goldman and Bachman (1958), Linder-Aronson (1970), Devgan and Leach (1979), Fujioka, Young and Girdany (1979) saw fit to code them into three progressive categories.

When Pruzansky (1975) divided the sizes of adenoids into four groups, he also documented that the sizes of the adenoids were not necessarily related to the sizes of tonsils in the same child.

The highest number of gradings was created by Holmberg and Linder-Aronson (1979), in a study involving nasal airway index, who subjectively evaluated the sizes of adenoids measured on lateral skull radiographs using a five-index scale as shown in Fig. 22.

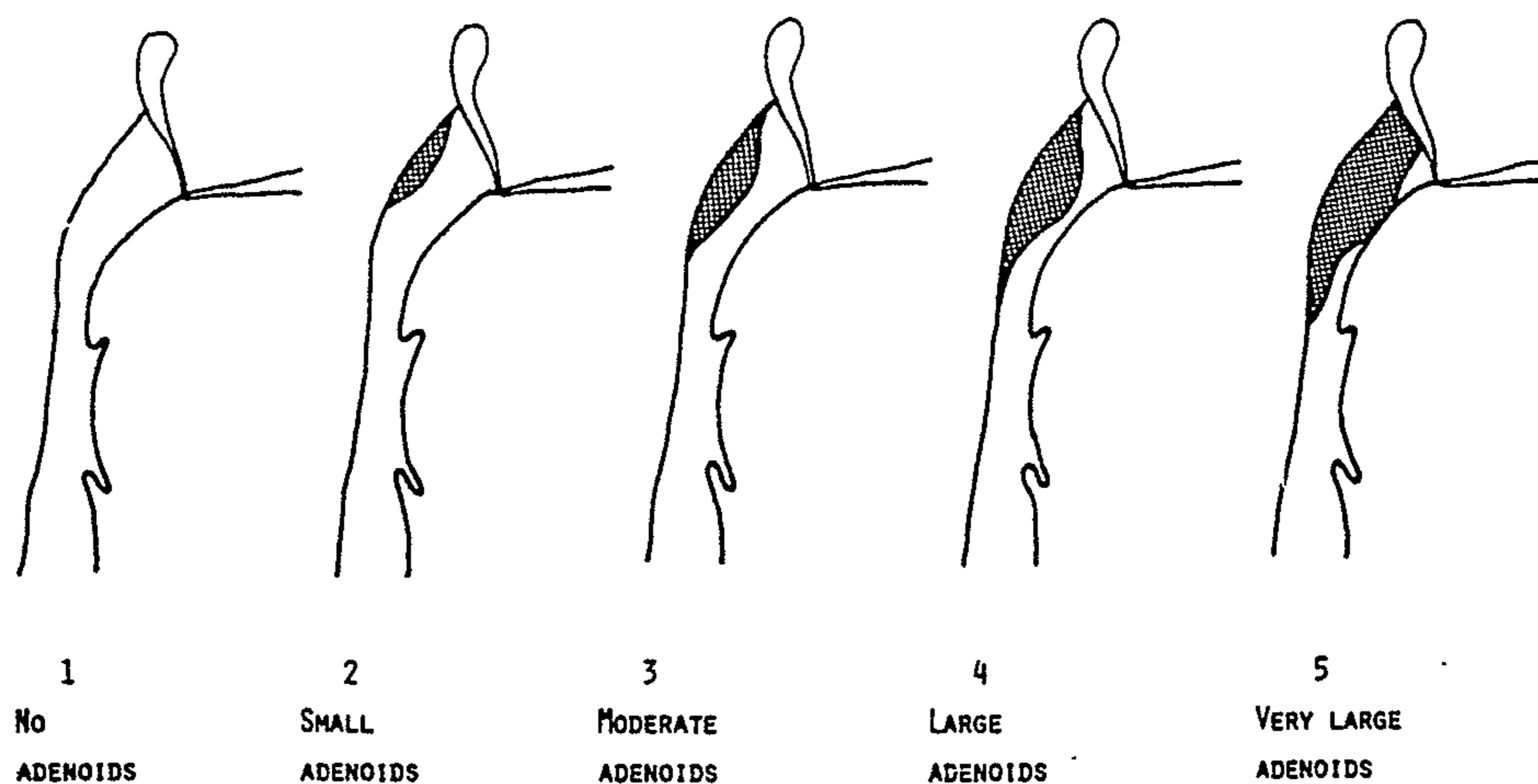


Fig. 22. A five-index scale to grade adenoids
(From Holmberg and Linder-Aronson 1979)

Subjective assessments of adenoidal and airway sizes are useful as a rough estimate, and almost invariably used as an adjunct to further clinical or radiographic evaluations.

4.4 ANGULAR AND LINEAR MEASUREMENTS

The notion of prescribing angular and linear parameters to define actual nasopharyngeal capacity dated back to 1929 when Schuller presented a paper on 'x-ray examination of deformities of the nasopharynx'. He specified transverse dimension of the nasopharynx on a lateral radiograph as a line drawn from the posterior edge of the hard palate to the projection formed by the anterior tuberculum of the atlas. The vertical dimension was regarded as the measurement of a vertical line drawn from the highest point of the roof of the pharynx to the already established horizontal line.

Schuller (1929) also suggested that the cranial base angle, i.e., that formed by the sphenoid plane and the clivus on the medial-sagittal section of the skull, is a reliable expression and directly correlated to nasopharyngeal depth. This conjecture was later confirmed by Ricketts (1954), Wildman (1961), Bergland (1963), and Maran, Gibb and Gibson (1971), but refuted by Engman, Spriestersbach and Moll (1965), and Schweiger (1966).

The original method of computing nasopharyngeal depth put forward by Schuller (1929) as afore-mentioned was later modified to be the distance between anterior tubercle of atlas and pterygomaxillary fissure by Brader (1957) and Wildman (1961).

In a cephalometric x-ray study of nasopharyngeal closure, Wolfe (1942) measured movements of the soft palate and the posterior wall of the pharynx and defined (GH) as the shortest distance from back wall to velum, a dimension of nasopharyngeal isthmus (Fig. 23).

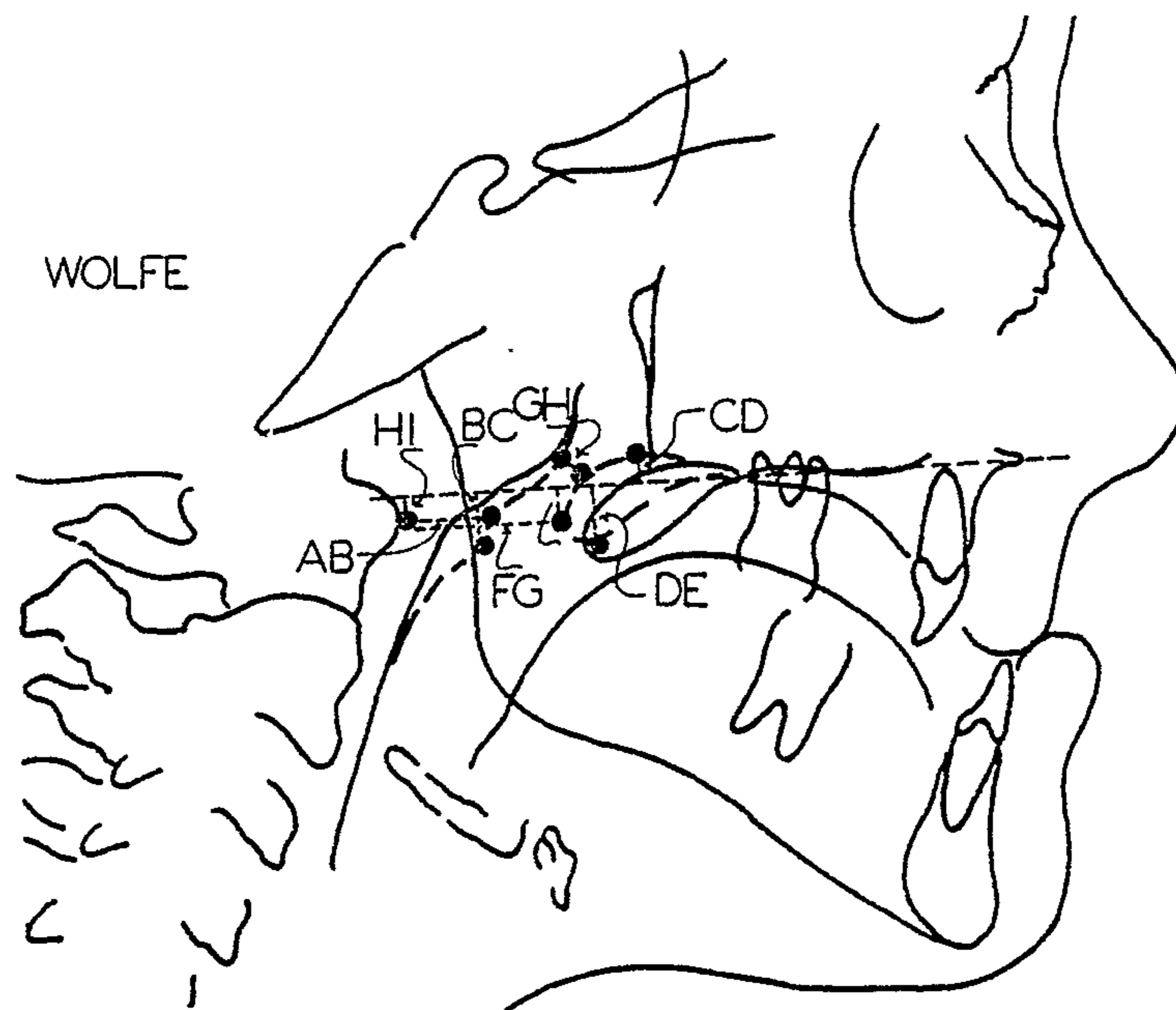


Fig. 23. Wolfe's measurements of the velopharyngeal area (From Wildman 1963)

This method was later adopted by Backlund (1963) in an investigation relating facial growth to malocclusion, and by Dunn, Green and Cunat (1973) in a study of nasopharyngeal airway size involving monozygotic twins.

Yip and Cleall (1971) modified the above method further by recording the width of nasopharyngeal isthmus at the level of the palatal plane rather than seeking the shortest possible distance in his studies of velopharyngeal function.

King (1952) used lateral cephalometric radiographs taken from the Broadbent-Bolton Growth Study to measure vertical and horizontal growth changes in the oral and nasopharynx. He used the Frankfort Plane as the basic reference line (Fig. 24), measured the distance between projections from anterior tubercle of atlas to that from pterygomaxillary fissure on Frankfort Plane, and signified this as the nasopharyngeal depth.

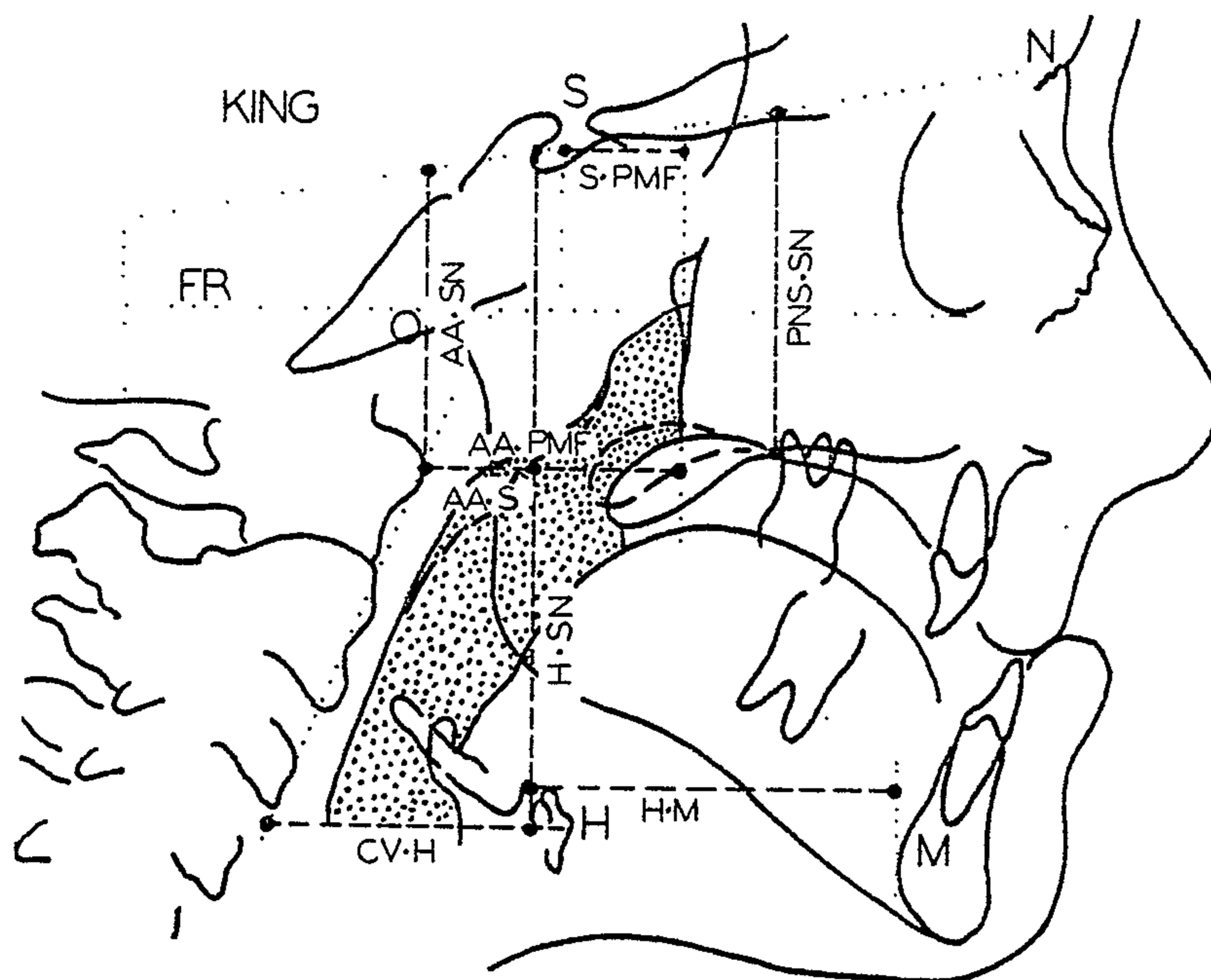


Fig. 24. King's system of measurements
(From Wildman 1961)

Ricketts (1954), in a study to determine the range of natural variation in the cranial base and its relation to contiguous anatomical structures, quantified nasopharynx in terms of antero-posterior and vertical distances, and amount of adenoid tissues present within the area bound by basion, sella, anterior tubercle of atlas and posterior nasal spine (Fig. 25).

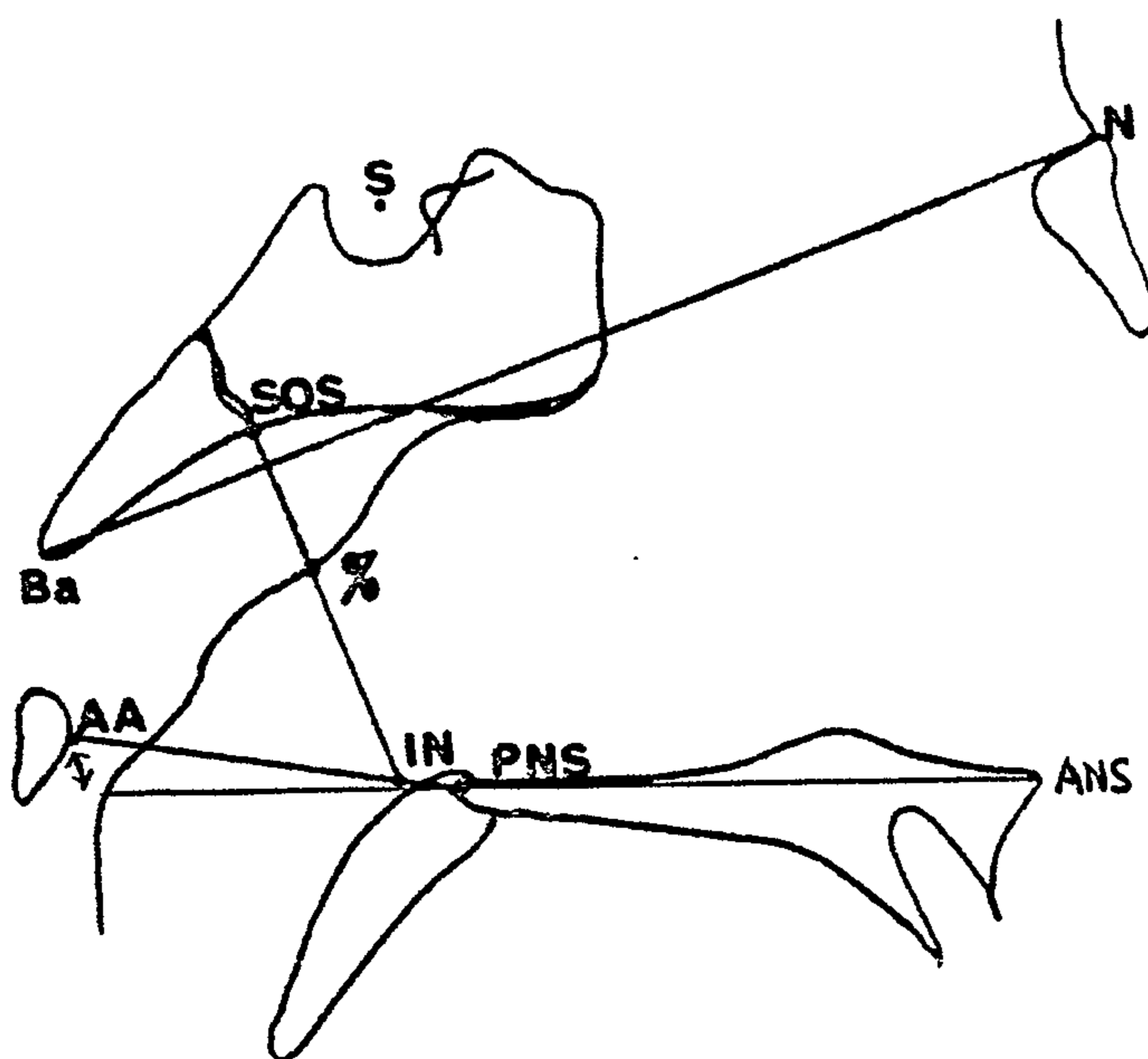


Fig. 25. Rickett's system of measurements
(Adapted from Preston 1979)

- (1) Antero-posterior dimension - measured by the angle $Ba-S-PNS$, and the distance $PNS-AA$ (AA is the most anterior point on the anterior arch of the atlas).
- (2) Vertical dimension - measured by the line which joins the spheno-occipital suture (SOS) to point IN (the inferior end of the perpendicular from SOS to line $PNS-AA$), and by the angle $S-Ba-PNS$.
- (3) The amount of adenoid tissue present is indicated by a percentage which equals the percentage of the line $SOS-IN$ covered with lymphoid tissue.
- (4) A measurement of nasopharyngeal depth to determine adenoid blockage of the nasopharynx - measured from pterygoid vertical (PTV) to the adenoid tissue, 5 mm superior to the palatal plane ($ANS-PNS$). He found this value an excellent discriminator between mouth breathers and nose breathers.

In an effort to study the width of the nasopharynx and related anatomic structures in normal and unoperated cleft palate children, Subtelny (1955) used the medial pterygoid plates of the sphenoid bone as a lateral delineation of nasopharynx. He defined, on a frontal cephalometric laminagraph, the distance between the inferior tips of the medial pterygoid plates (bihamular measurement) as the width of nasopharynx.

Brader (1957), in an analysis of spatial relationship of pharyngeal structures in cleft and normal subjects, evaluated antero-posterior dimension of nasopharynx and adenoid tissue size within the framework of anterior tubercle of atlas, basion, sella, pterygomaxillary fissure, and hyoid bone (Fig. 26).

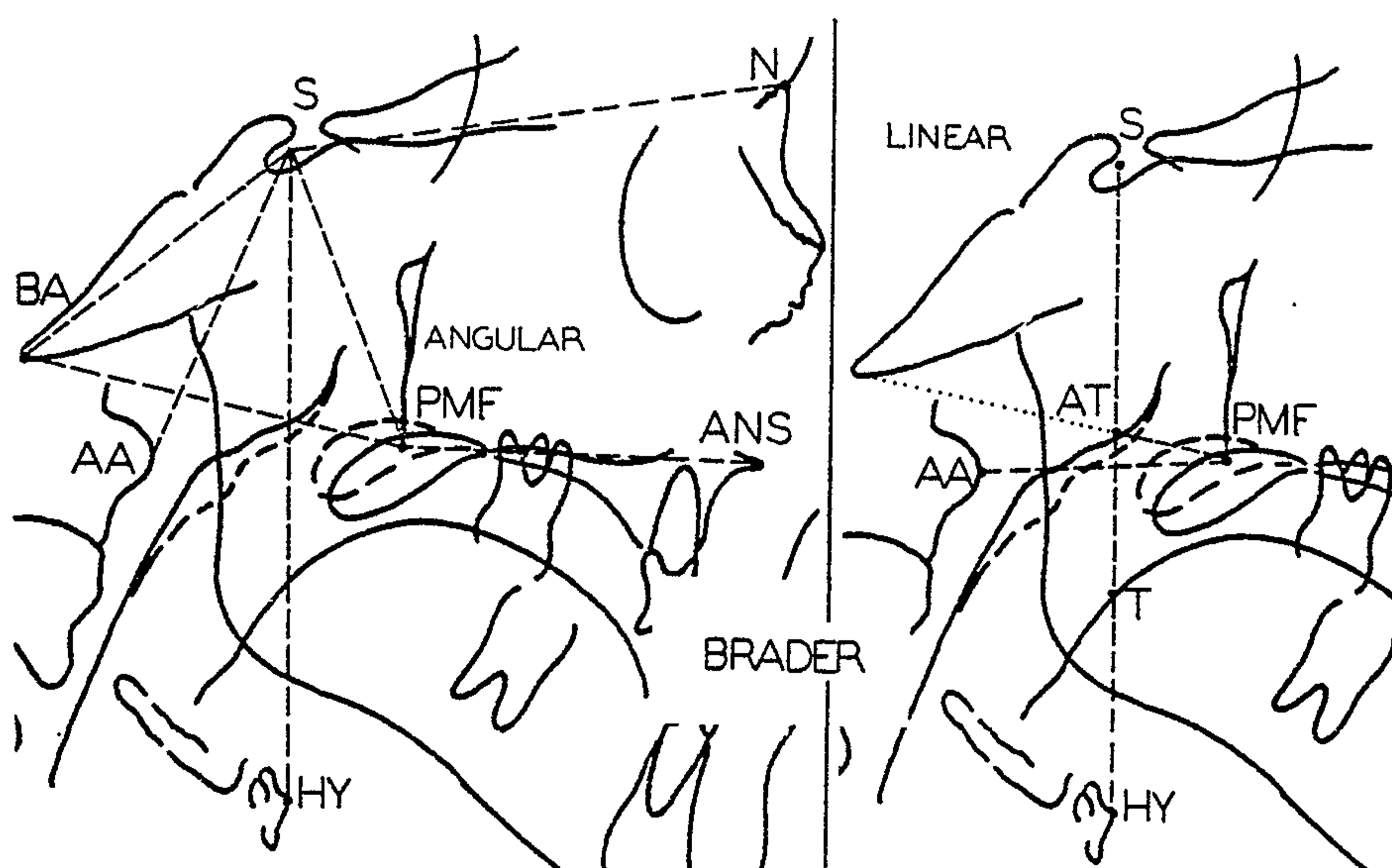


Fig. 26. Brader's linear and angular measurements (From Wildman 1961)

- (1) Antero-posterior dimension - measured by angle $AA-S-PMF$, as degree of interspace between anterior tubercle of atlas and pterygomaxillary fissure. Also by angle $Ba-S-PMF$, as degree of interspace between basion and pterygomaxillary fissure.
- (2) Adenoid tissue - measured by the value $AT-PMF$, as distance between outline of adenoid tissue and pterygomaxillary fissure along line joining basion and pterygomaxillary fissure. Also by the value $\frac{S-Ba-AT}{S-Ba-PMF} \times 100\%$, as amount of adenoid tissue.

The cranial base line, i.e., nasion-basion plane, was viewed by Subtelny (1957) to effectively delineate the base of the skull from the face and pharynx. In a study of the growth of soft palate, he defined on a lateral cephalometric radiograph horizontal dimension of the nasopharyngeal space as the distance from the posterior nasal spine (PNS) to the posterior pharyngeal wall (PH) as measured along the palatal plane (Fig. 27). The height is represented by the distance between PNS and the cranial base line as measured along a perpendicular to the palatal plane passing through PNS.

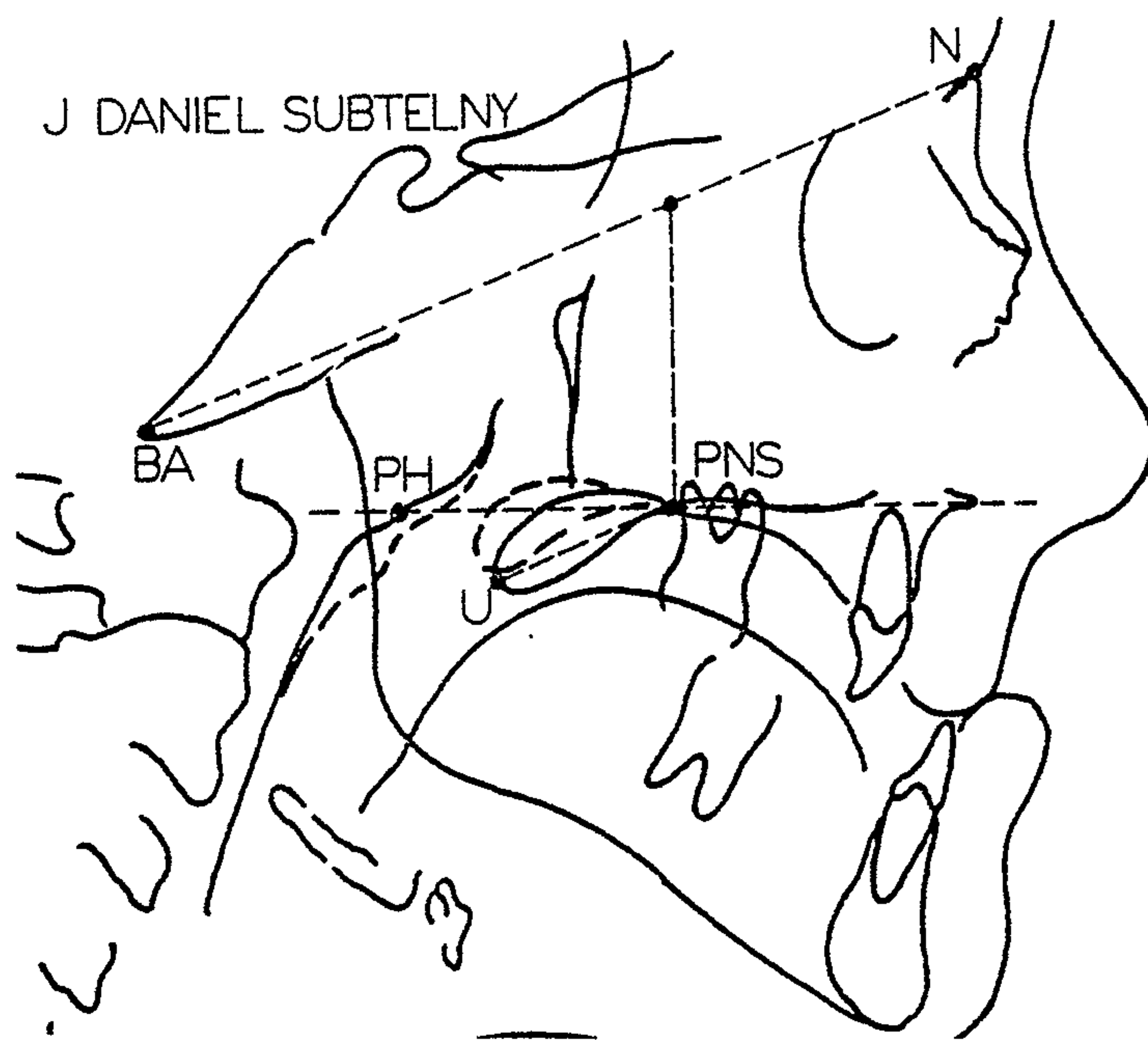


Fig. 27. Daniel Subtelny's system of measurement
(From Wildman 1961)

This method of applying height and depth to quantify nasopharyngeal space has been favoured by numerous authors subsequently (Schweiger 1966; McCarthy, Coccaro and Schwartz 1979). A refinement was carried out by Coccaro, Pruzansky and Subtelny (1967) in substituting PNS with pterygomaxillary fissure, the latter being more readily discernible on a radiograph.

Along a similar line, an even further modification was offered by Mazaheri, Krogman, Harding, Millard and Mehta (1977) when they discarded the use of cranial base line as the superior limit of nasopharyngeal height, and replaced it by a soft tissue boundary designated as superior pharyngeal wall (SPW) measured along a perpendicular line to the palatal plane (Fig. 28). The variable factor of loose tissue space between the cranial base and superior border of nasopharyngeal airway is thereby eliminated.

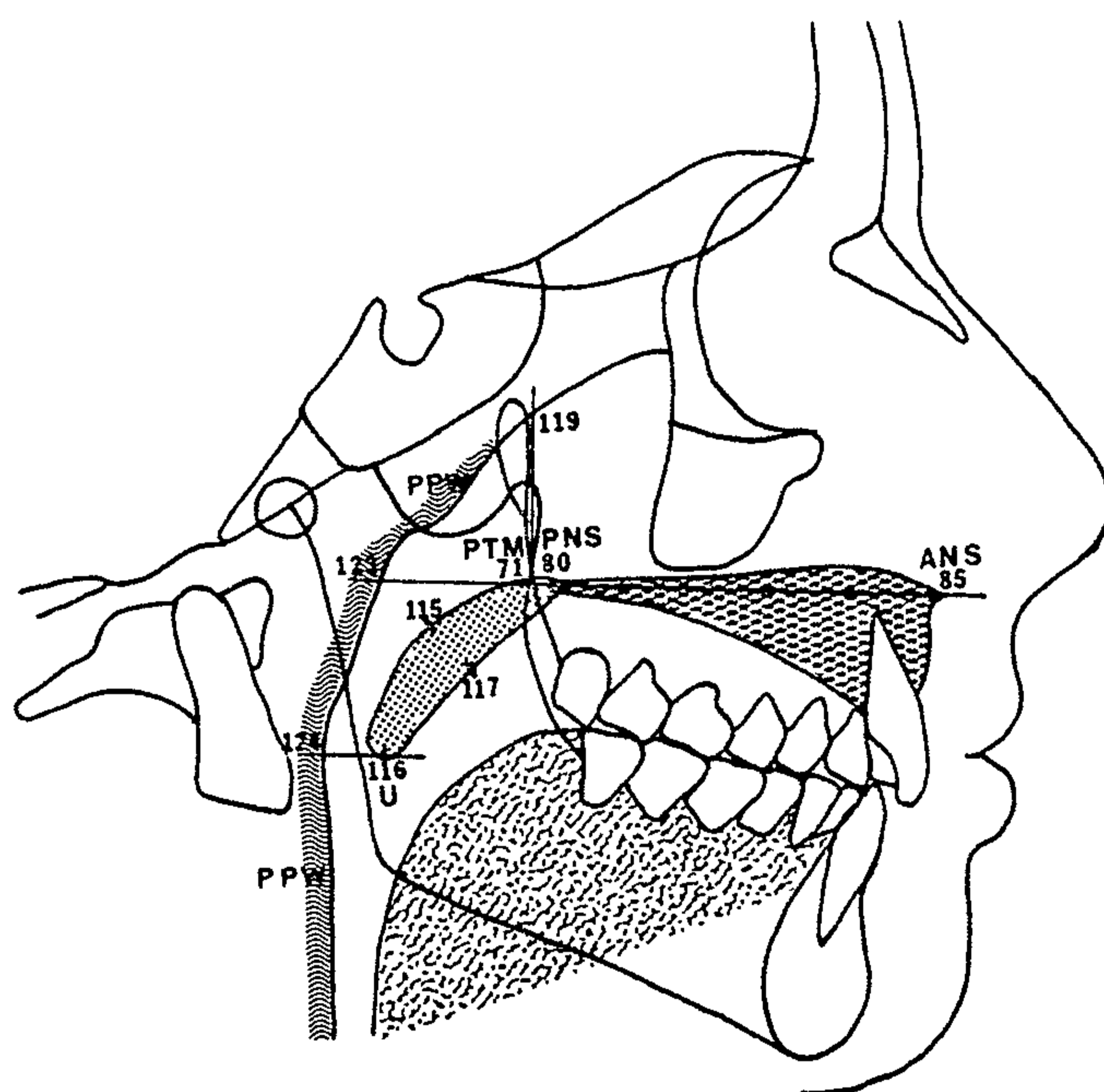


Fig. 28. Digitized cephalometric tracing of the velopharyngeal region (Mazaheri et al 1977)

In an extensive study of the variation of the skull in different races, Bergland (1963) compared the dimensions of bony nasopharynx as limited by basion, tuberculum pharyngicum, hornion and staphylion, giving values for roof angle and linear measurements between Lapps and Norwegians (Fig. 29a, 29b).

a

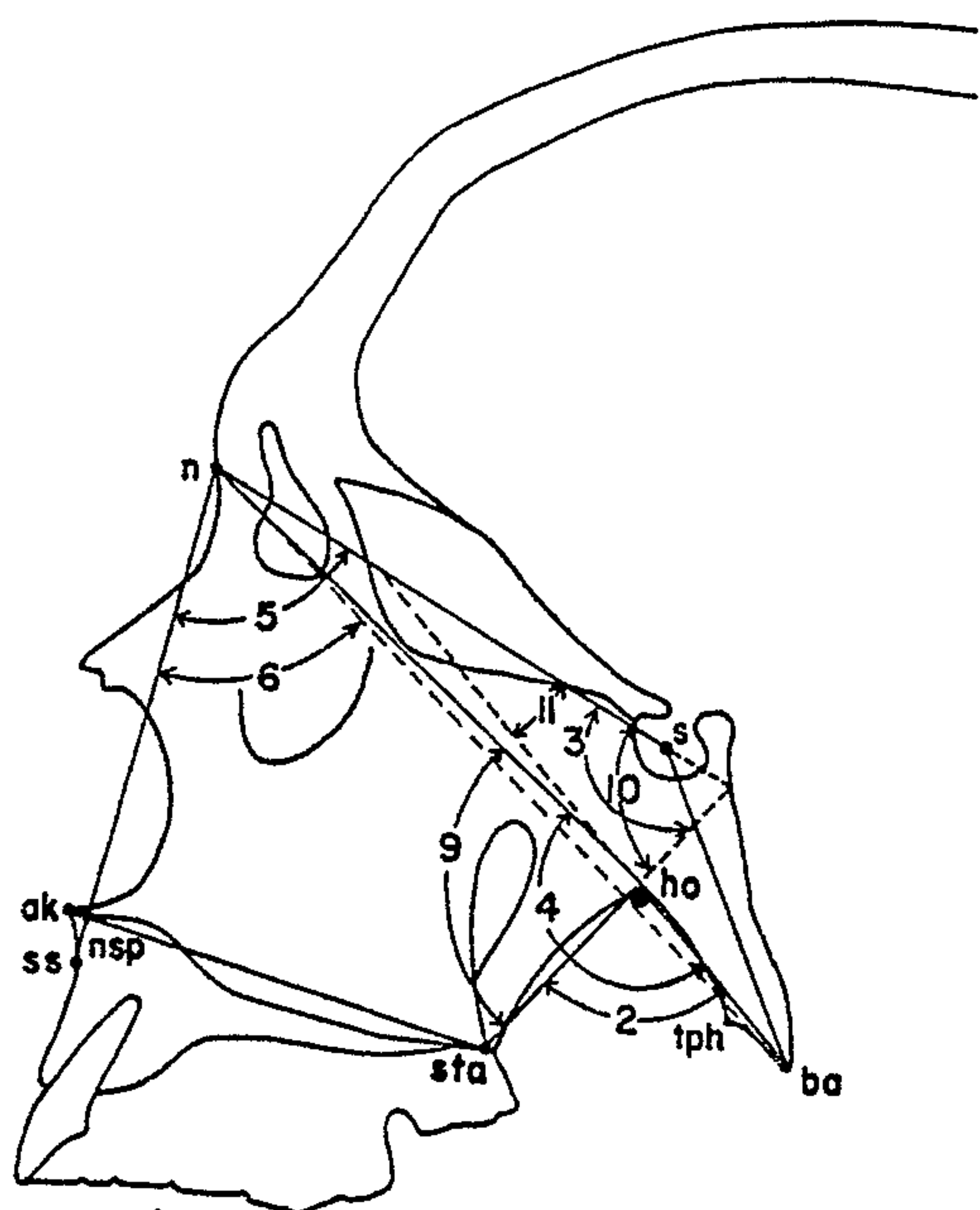


Fig. 29a. Angular measurements on lateral skull radiograph.

b

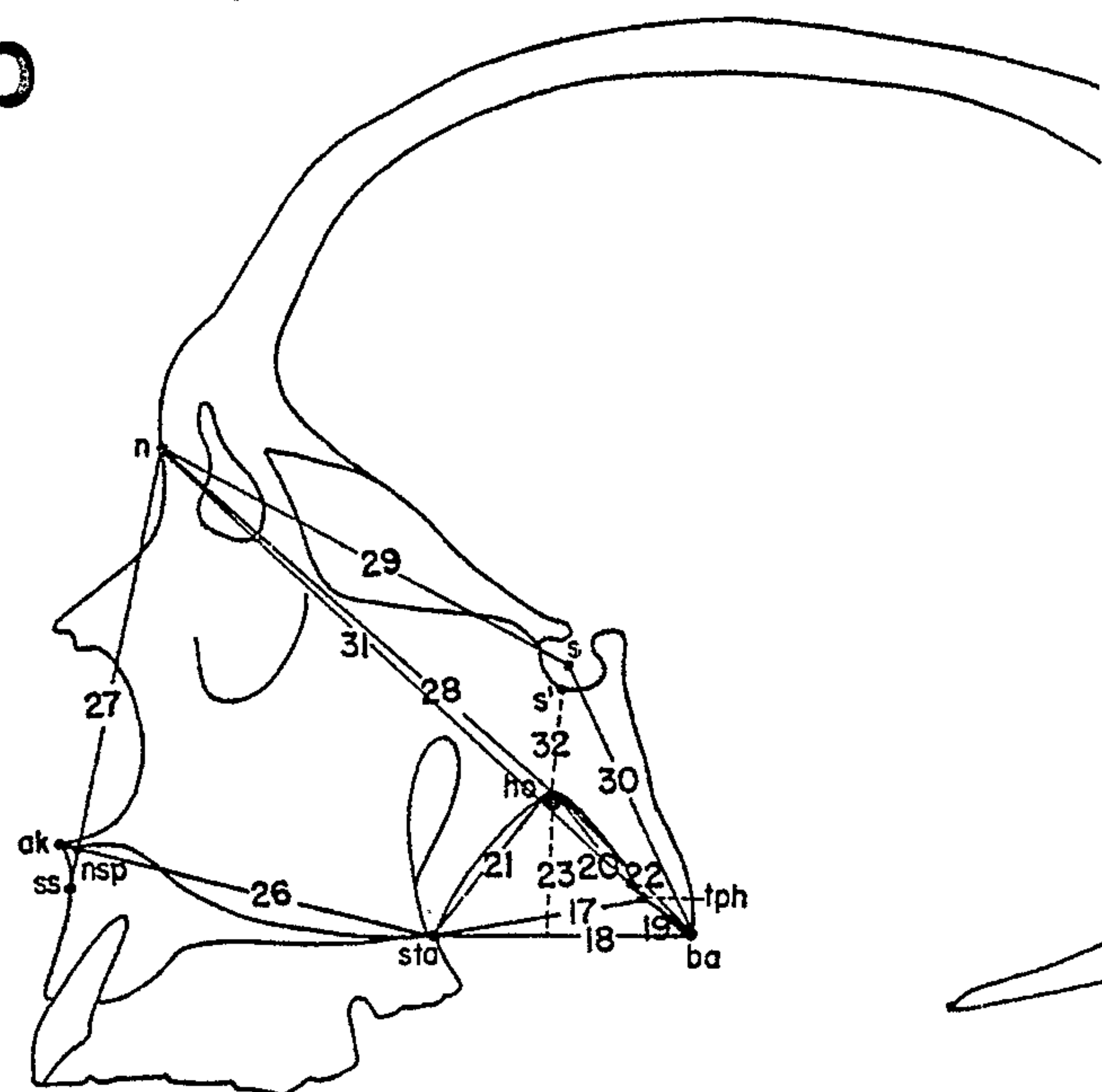


Fig. 29b. Linear measurements on lateral skull radiograph.

(From Bergland 1963)

Roof angle (2) = $sta-ho-ba$;

Intra-pharyngeal depth (17) = $sta-tph$;

Total depth (18) = $sta-ba$;

Height = perpendicular on $sta-ba$ through ho ;

Width = choanal width, or greatest distance between medial pterygoid plates;

Index $\frac{sta-tph (17)}{sta-ba (18)} \times 100\%$ = the relation between the intrapharyngeal depth and the total depth of bony nasopharynx.

Definitions applied:

ba: point of intersection between the median sagittal plane and the anterior border of foramen magnum;

ho: the vomer's most dorsal contact point on the body of the sphenoid bone in the medial sagittal plane between the alae of vomer;

tph: point of intersection between the median sagittal plane and the line of attachment of the membrana pharyngobasialis;

sta: the tip of the posterior nasal spine.

Engman, Priestersbach and Moll (1965) were unable to find any relationship between nasopharyngeal depth and the four ways of defining cranial base angles measured within the confines of pterygomaxillary line, sella, anterior point of occipital condyle, and anterior point of atlas. Like King (1952), they preferred to use Frankfort Horizontal as a reference line on which perpendiculars

were dropped from points delineated nasopharyngeal depth (Fig. 30).

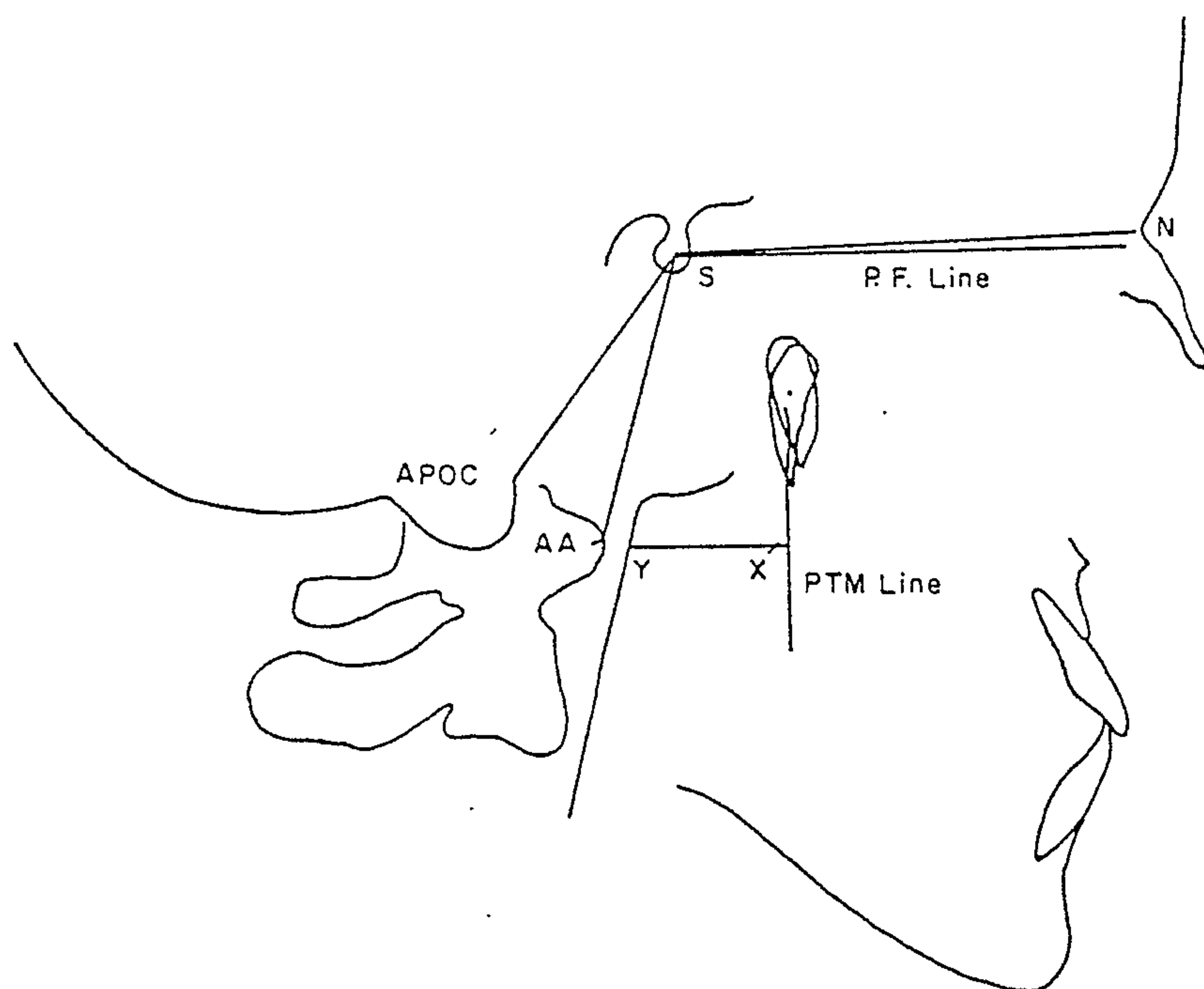


Fig. 30. Landmarks used by Engman et al
(From Engman et al 1965)

Cranial angles measured:

- (1) *N-S-APOC = the inferior angle formed by the line connecting nasion, sella, and the most anterior point of the occipital condyle.*
- (2) *N-S-AA = the inferior angle formed by the line connecting nasion, sella, and the most anterior point on the atlas.*
- (3) *PF-S-APOC = the inferior angle formed by intersection of a line drawn from sella, parallel to the Frankfort plane, with a line from sella to the most anterior point of the occipital condyle.*
- (4) *PF-S-AA = the inferior angle formed by the intersection of a line drawn from sella, parallel to the Frankfort Plane, with a line from sella to the most anterior point on the atlas.*

Nasopharyngeal depth measured as distance between X and Y where:

X = the point of intersection of the PTM line with a line parallel to the Frankfort Plane and originating at AA;

Y = the point where a line from AA, parallel to the Frankfort Plane, intersects the posterior pharyngeal wall;

PTM = a line drawn through the mid-point of pterygomaxillary fissure and perpendicular to Frankfort Plane.

It was felt by the authors that the above landmarks selected to denote cranial base angulations are more reliably located than the often-used nasion-sella-basion. For the same reason, a line was chosen to represent the anterior limit of the nasopharyngeal depth instead of a point.

Schweiger (1966), however, found it possible to locate PMF which he defined as a point on the posterior surface of the left maxilla at the intersection of the palatal plane, and employed the angle APOC-S-PMF to indicate the bony depth of nasopharynx in cleft subjects. He nonetheless adopted Subtelny's (1957) method to evaluate soft tissue nasopharyngeal depth (Fig. 31).

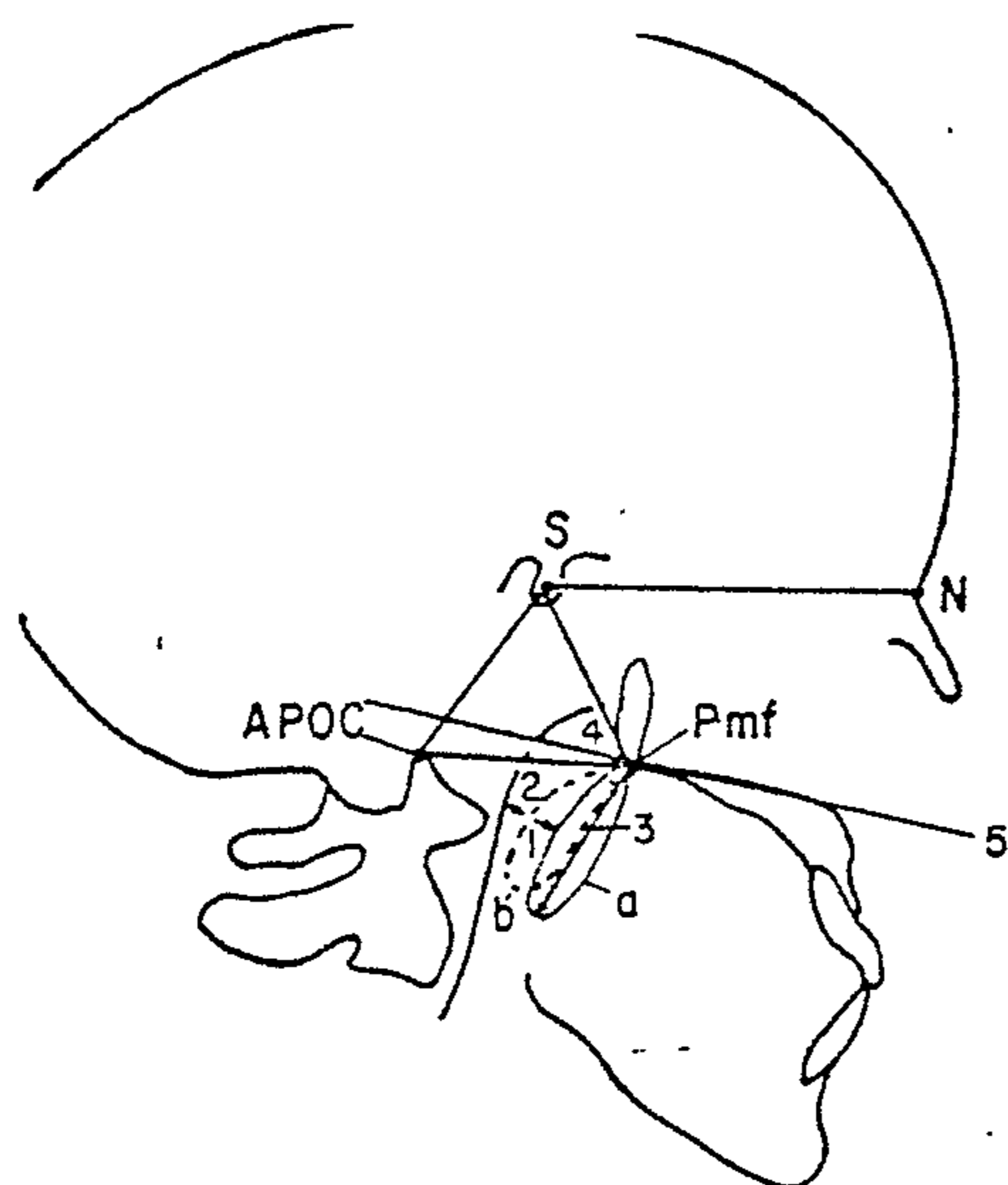


Fig. 31. Schweiger cephalometric landmarks
(From Schweiger 1966)

In contrast to the complex system designed by preceding researchers, Johannesson (1968) simply measures the greatest width of the soft tissue outline anterior to the site of the pharyngeal tubercle on true lateral radiographs perpendicular to the bony roof of the nasopharynx.

Likewise, Capitanio and Kirkpatrick (1970) draw a line from the posterior clinoids perpendicular to the base of the sphenoid bone and then to the margin of the soft tissue as outlined by air in the nasopharynx on a lateral radiograph. The distance along this line from the base of the skull to the margin of the soft tissue in the nasopharynx in centimeters is regarded as the amount impeding the airway.

While studying possible associations between the size of nasopharynx and Class II malocclusion, Mergen and Jacobs (1970) measured nasopharyngeal depth as the linear distance (X) from point PNS to

the point of greatest concavity or convexity of the posterior nasopharyngeal wall (Fig. 32). In this way, adenoids are assessed where they are most prominent and presumably a more reliable test of airway occlusion.

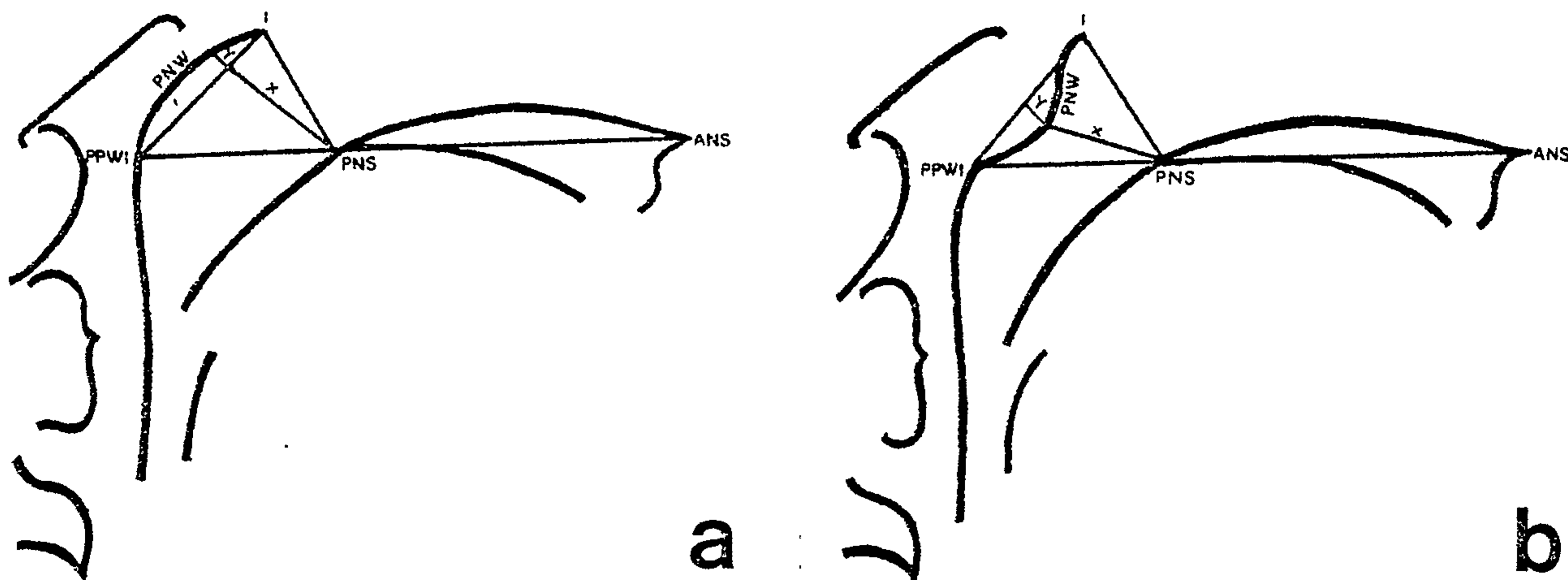


Fig. 32. Mergen and Jacobs measurements, posterior pharyngeal wall concave (a) and convex (b) (From Mergen and Jacobs 1970)

Depth of concavity or convexity as indicated by a linear line (Y) which is the distance from the most prominent point on the posterior nasopharyngeal wall (PNW) to the reference line (r) measured by means of a line perpendicular to the PPWI-I line, where:
PPWI = posterior pharyngeal wall intersection by palatal plane.
I = point of intersection on posterior pharyngeal wall by PNS-S line.

Although frontal radiographs were used in Linder-Aronson's (1970) comprehensive study of adenoids and their effects on dentofacial characteristics, lateral cephalometric radiographs gave most of the radiographic readings needed. The variables he designated to quantify nasopharynx have been extensively used by other researchers since.

The system of measurements is based on a triangle adopted from Bergland (1963) so that adenoids are assessed along lines formed on the triangle pterygomaxillare-hormion-basion or expressed as areal measurements within those confines (Fig. 33).

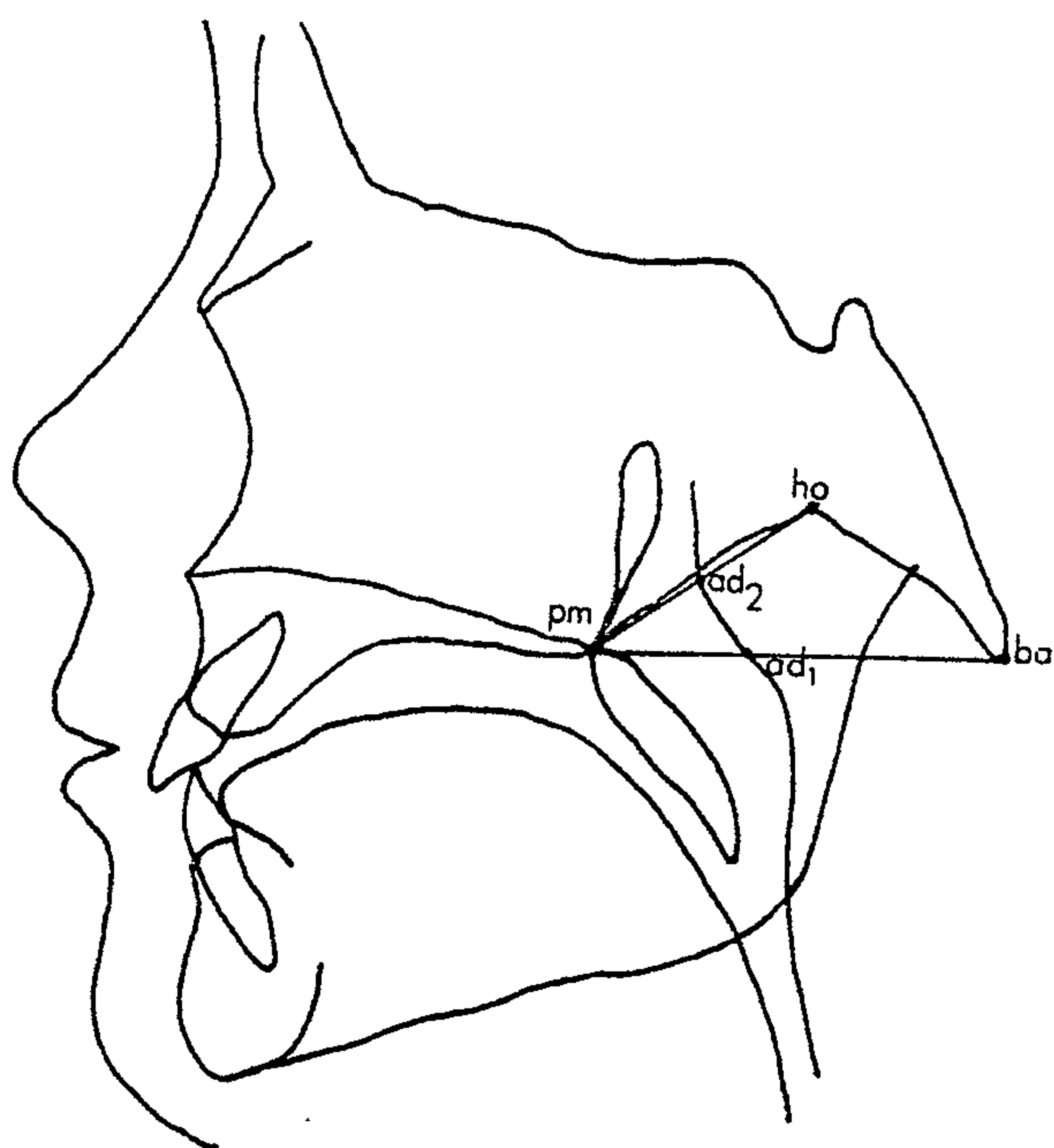


Fig. 33. Adenoid measurements by Linder-Aronson
(From Holmberg and Linder-Aronson 1979)

Relevant nasopharyngeal variables used:

$ad_1 - ba$ = thickness of adenoids along the line pm-ba.

$ad_2 - ba$ = thickness of adenoids along the line pm-ho.

$\frac{ad_1 - ba}{pm-ba}$ = thickness of adenoids along the line pm-ba in relation to depth of bony nasopharynx.

$\frac{ad_2 - ba}{pm-ho}$ = thickness of adenoids along the line pm-ho in relation to length of dorsal edge of vomer.

pm-ba = depth of bony nasopharynx.

ho / pm-ba = height of bony nasopharynx, perpendicular to line pm-ba through hormion.

ad_1 = intersection of the line pm-ba and the posterior pharyngeal wall.

ad_2 = intersection of the line pm-ho and the posterior pharyngeal wall.

In later studies of a similar nature, the point hormion was replaced by a mid-point (S_0) on the line sella-basion (Linder-Aronson and Henrikson 1973; Henrikson, Linder-Aronson and Westborg 1975). The point ad_2 was therefore taken as the intersection of the posterior pharyngeal wall and the line pm- S_0 .

Because of their high statistical significance with mouth breathing (Schulhof 1979), the values ad_1 -pm and ad_2 -pm provide reliable tests

for incidence of mouth breathing without resorting to areal or volumetric measurements (Linder-Aronson and Henrikson 1973).

Eller, Roberts and Ziter (1971), while studying normal nasopharyngeal soft tissues in adults utilised the following:

- (1) The posterior wall is the thickness of the soft tissue along a line (B) extending from the basion to the posterior edge of hard palate.
- (2) The roof thickness is measured 2 cm from the basion perpendicular to a line (A) drawn along the base of the skull.
- (3) Cranial base angle is the angle formed by lines (A) and (B).

Being sceptical about the reliability of point locations, Osborne, Pruzansky and Koepp-Baker (1971), and probably influenced by Engman, Spriestersbach and Moll (1965), prefer to use planes. They decided that the osseous nasopharyngeal depth should be regarded as the linear distance between a plane drawn perpendicular to the palatal plane registered on pterygomaxillary fissure and a second one constructed perpendicular to the palatal plane registered on the anterior-most point of the first cervical vertebra (Fig. 34).

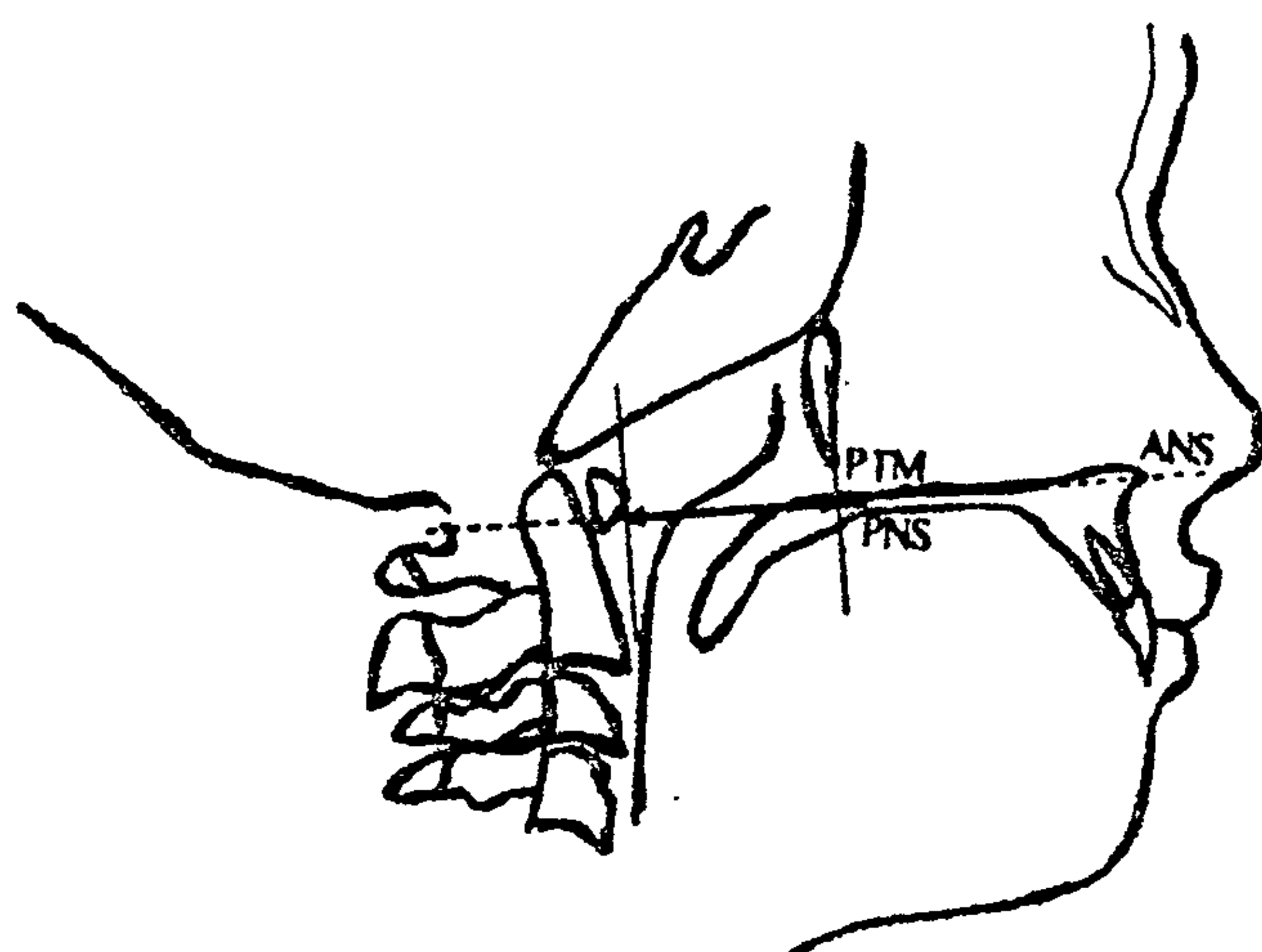


Fig. 34. Nasopharyngeal depth
(From Osborne, Pruzansky and Koepp-Baker 1971)

Conceiving a similar idea to Mergen and Jacobs (1970), Maran, Gibb, Gibson and Asbury (1971) resorted to measure adenoids at the point of maximum thickness while avoiding variations arising from undesirable head postures.

Generally agreeing to the validity of using nasion-sella-basion to indicate cranial base angle, Maran et al (1971) included a point located at the antero-inferior margin of the socket of upper central incisors to compute nasopharyngeal depth. They did, however, concede the laborious nature and the requirement of strong illumination in executing the method to be described next (Fig. 35).

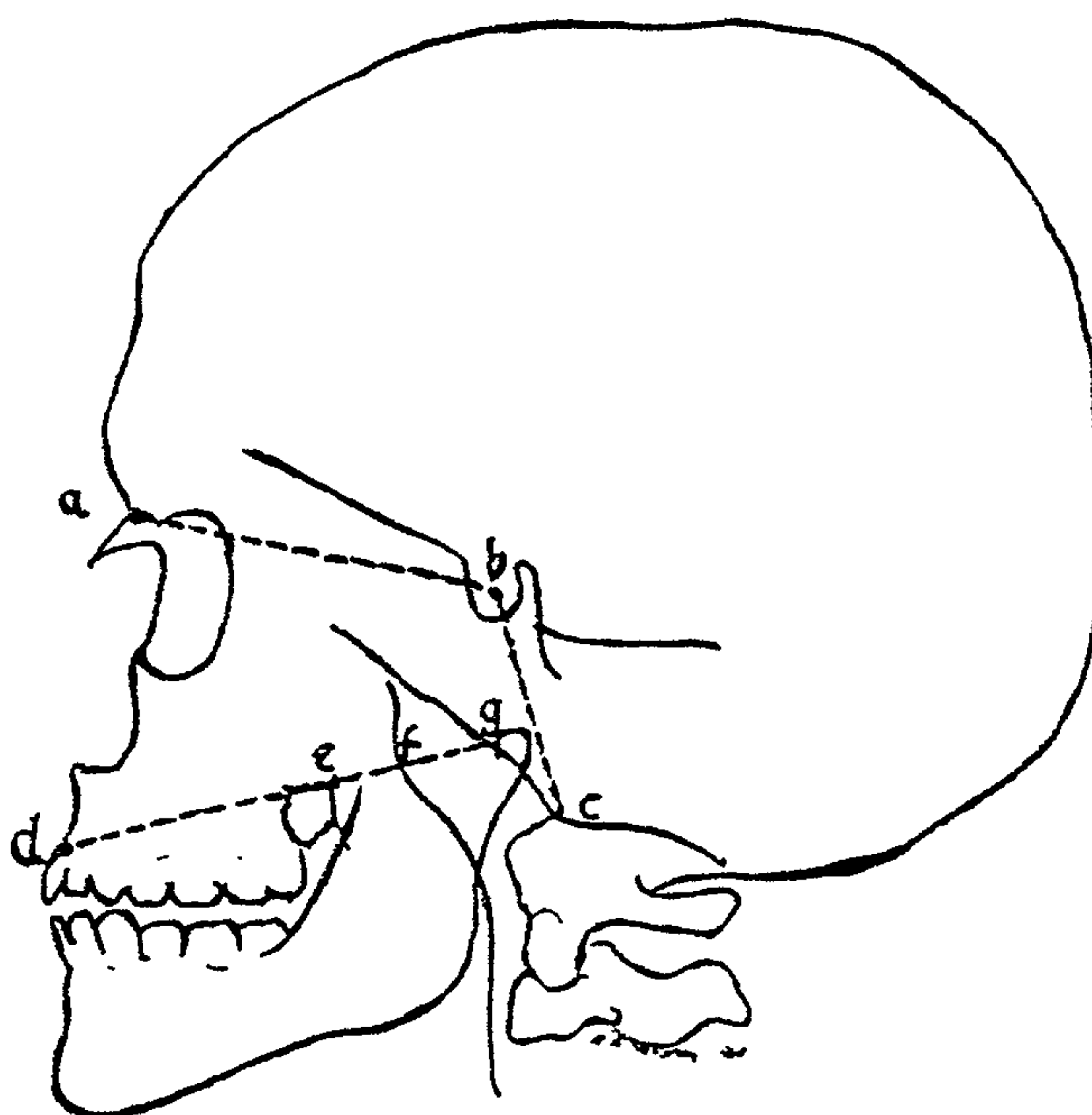


Fig. 35. Nasopharyngeal depth
(From Maran et al 1971)

Nasopharyngeal depth is measured on a line joining the antero-inferior margin of the socket of the upper central incisors (d), to the posterior bony edge of the hard palate (e), projected posteriorly to cross the base of the skull (g). The nasopharyngeal depth is the distance along this line between (e) and the anterior margin of the clivus (g). Adenoid depth is the value (f) to (g).

In a study of the linear growth of the pharyngeal cavity, Castelli, Ramirez and Nasjleti (1973) defined the dimension of nasopharyngeal isthmus as the distance from the most anterior and superior point of the pharyngeal roof to the dorsum of the soft palate over the posterior nasal spine (i.e., AC in Fig. 36).

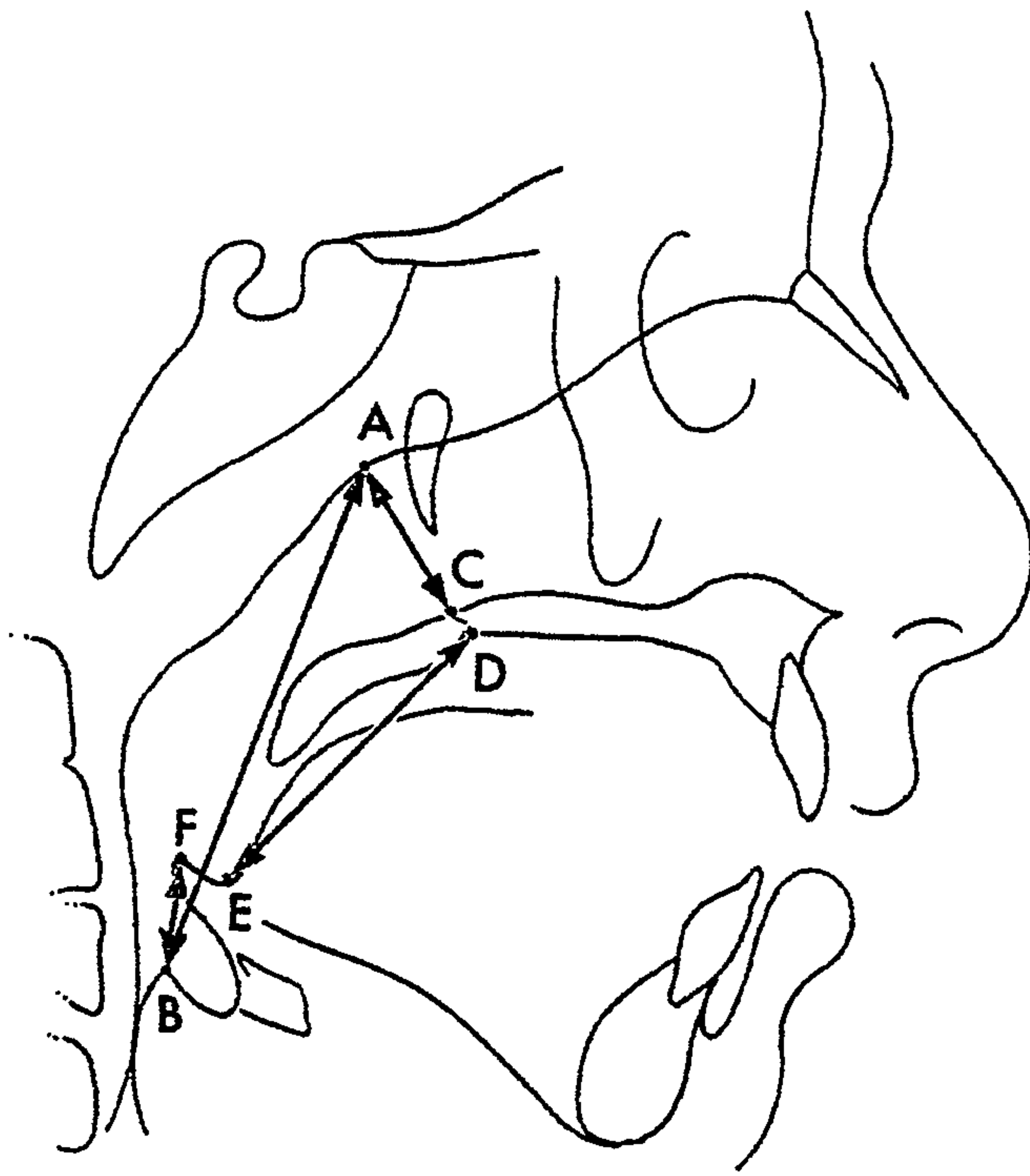


Fig. 36. Sagittal dimensions of pharynx
(From Castelli, Ramirez and Nasjleti 1973)

This is not to be confused with the method of Mazaheri et al (1977) where the measurement is made along a perpendicular line to the palatal plane. Again, the advantage of the Castelli method is to include the most extreme delineating point of the roof of nasopharyngeal airway, and the same concept was perceived by Mergen and Jacobs (1970), though in a postero-superior aspect.

Khoo, Lee, Ng and Tye (1974), while assessing normal and pathological states of the soft tissue nasopharynx, described four sagittal diameters of the roof and posterior walls. They comprised of distances measured at the levels of the basisphenoid, basion, the first and the second cervical vertebrae (Fig. 37). Means of all four diameters were established and compared to those measured by Johannesson (1968). It was observed that a large departure from the norms occurred in a large percentage of subjects with nasopharyngeal tumours.

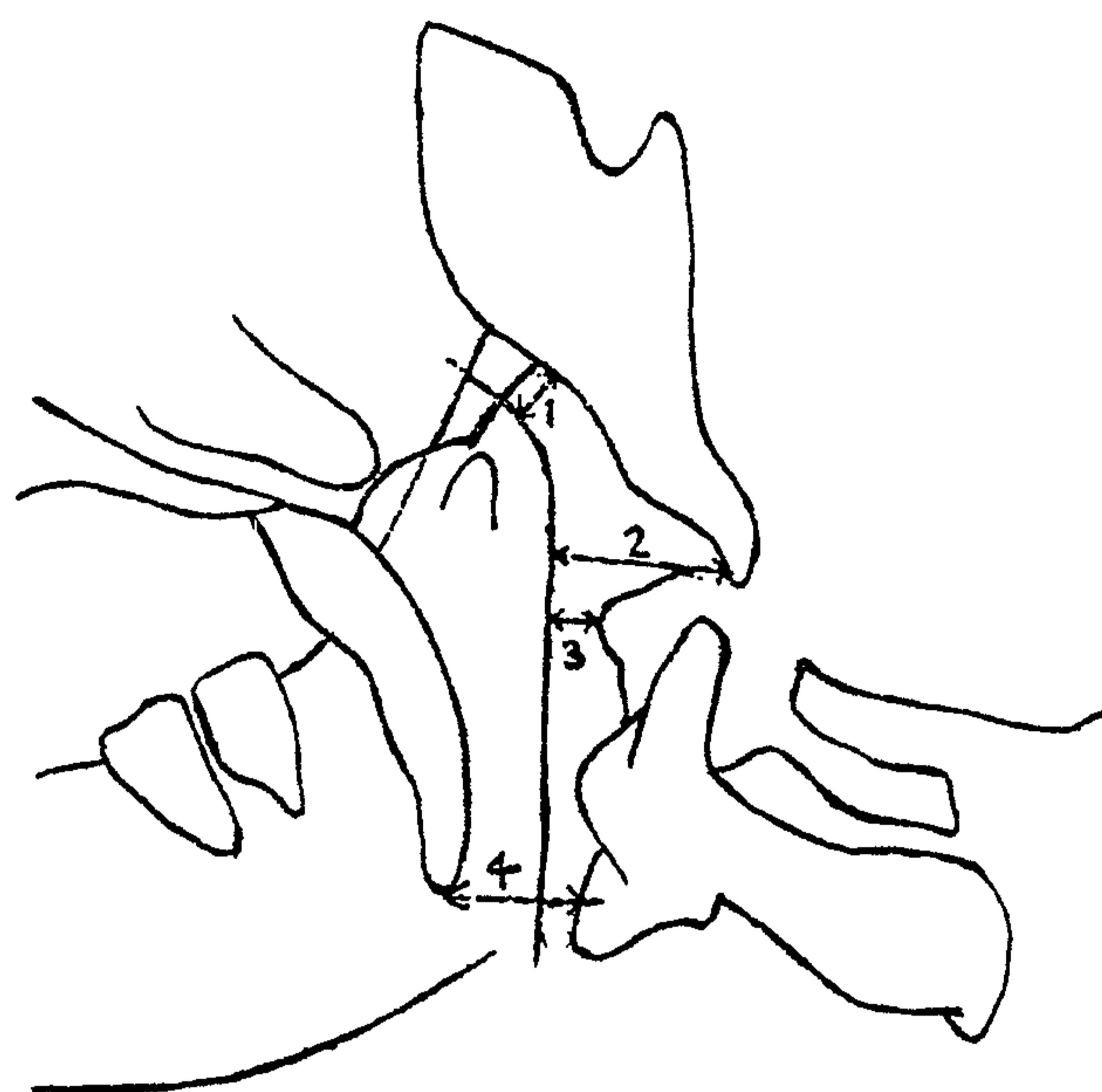


Fig. 37. Four diameters of nasopharynx
(From Khoo et al 1974)

The four diameters measured are:

- (1) *Roof:* the length of the perpendicular dropped from the basion to end at the inferior border of the roof, at the most convex point for convex roofs and the most concave point for concave roofs.
- (2) *FM:* basion to posterior pharyngeal wall.
- (3) *C1:* anterior point of atlas to posterior pharyngeal wall.
- (4) *C2:* from the most prominent point of the body of the axis, usually at its lower half, to the posterior pharyngeal wall.

A nasopharyngeal area was derived mathematically by Handelman and Osborne (1976), using four skeletally defined lines which formed a trapezoid. They questioned the reliability of triangular limits of bony nasopharynx as used by Bergland (1963) and followed by Linder-Aronson (1970). Adenoids were seen to lie anterior to the triangle formed by pterygomaxillare, hormion and basion. Basion has little direct influence on limits of the posterior pharyngeal wall anyway. The trapezoid analysis was recommended because it reflects better the limits of the bony nasopharynx (Fig. 38).

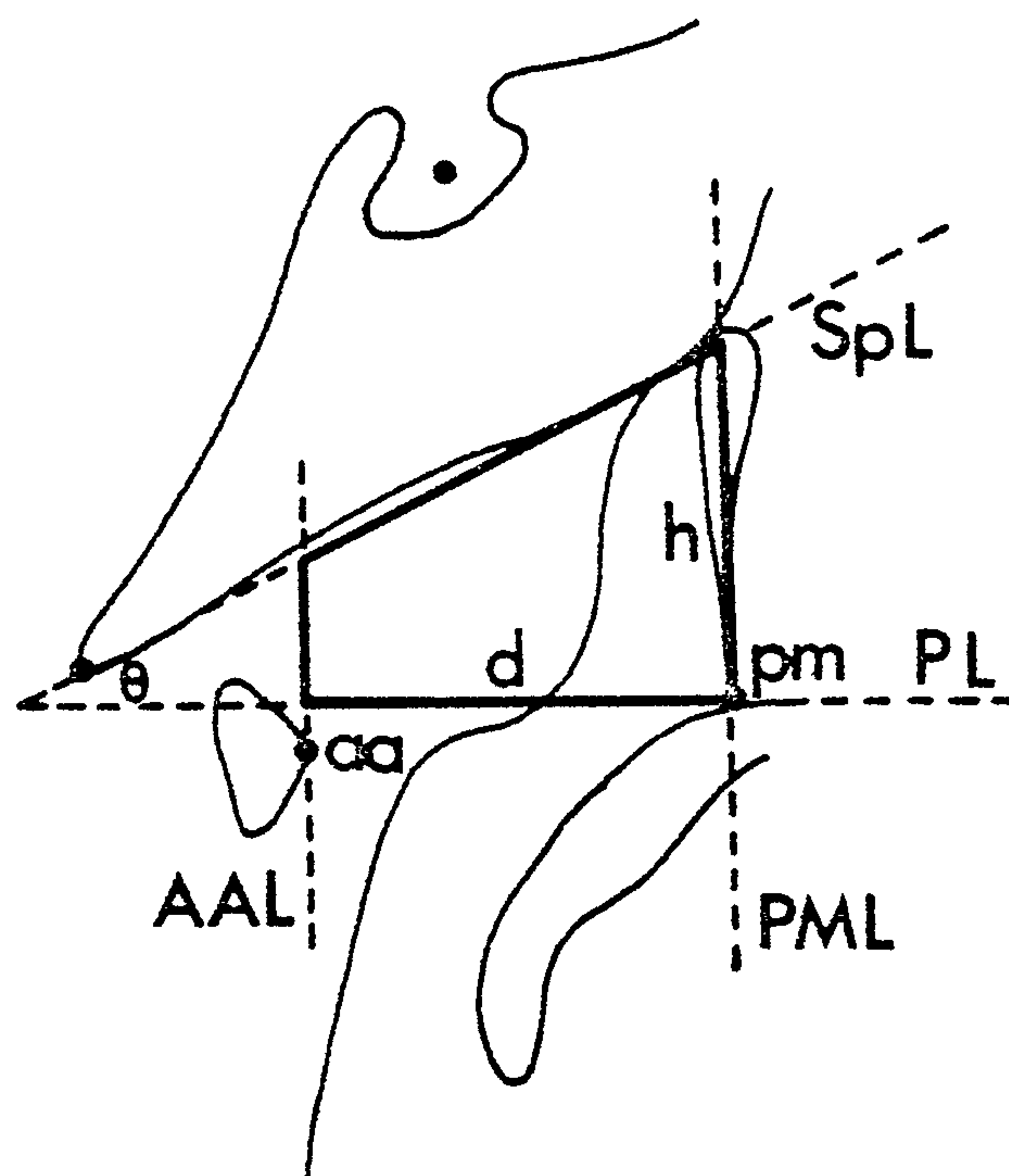


Fig. 38. The Trapezoid Analysis
(From Handelman and Osborne 1976)

Nasopharyngeal depth (d): the distance between the perpendicular intersections of anterior atlas line (AAL) and pterygomaxillary line (PML) along the palatal plane (PL).

Nasopharyngeal height (h): the distance between the intersections of palatal line and sphenoid line (SpL) along the pterygomaxillary line.

The authors, however, admitted two limitations to this analysis. Firstly, the posterior dimension is dependent on position of atlas which may change during extension or flexion of the cervical vertebrae. Secondly, no consideration is given to the width of nasopharynx which is difficult to assess from antero-posterior radiographs anyhow.

Hibbert and Whitehouse (1978) measured the depth of nasopharyngeal airway as the shortest distance between the apex of the adenoidal mass to the posterior wall of the antrum.

It is also of interest to know that Quick and Gundlach (1978), in a study of 'adenoid facies', quantified nasopharynx according to the dimensions of its oral and nasal exits. The sagittal diameter

of the nasopharynx is the distance between the posterior nasal spine and the midpoint of the anterior margin of the atlanto-occipital joint and corresponds to the exit into oral pharynx. The oblique diameter is defined as that between PNS and sella and corresponds to the entrance into the nasopharynx from the nose.

Frustrated by the inadequacy of previous adenoidal measurements, and feeling strongly that the absolute size of the adenoids and the size and shape of the nasopharyngeal space are major factors that determine nasopharyngeal obstruction, Fujioka, Young and Girdany (1979) developed an adenoidal-nasopharyngeal ratio (AN ratio) derived from linear measurements on lateral radiographs of the nasopharynx (Fig. 39a, 39b).

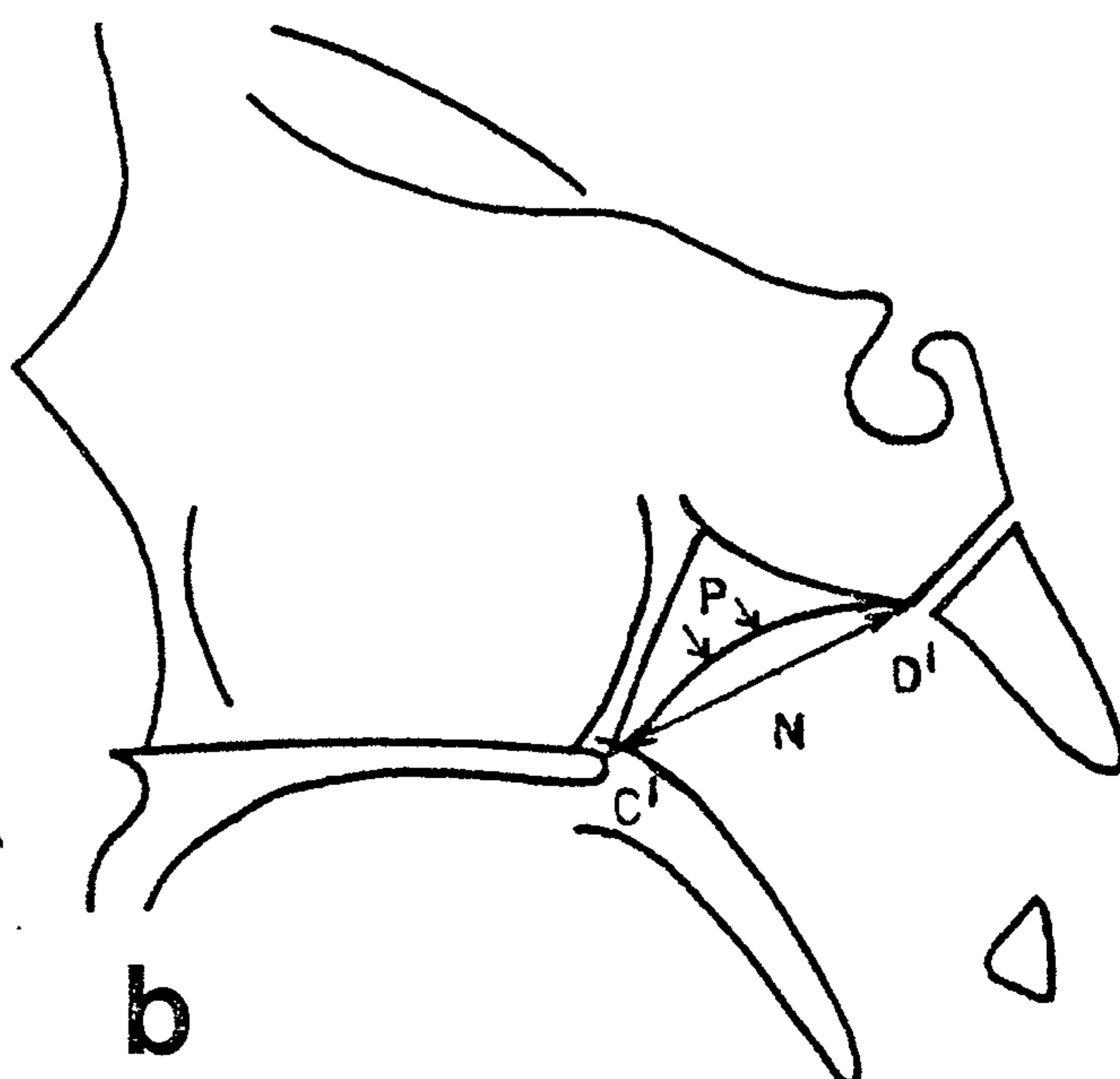
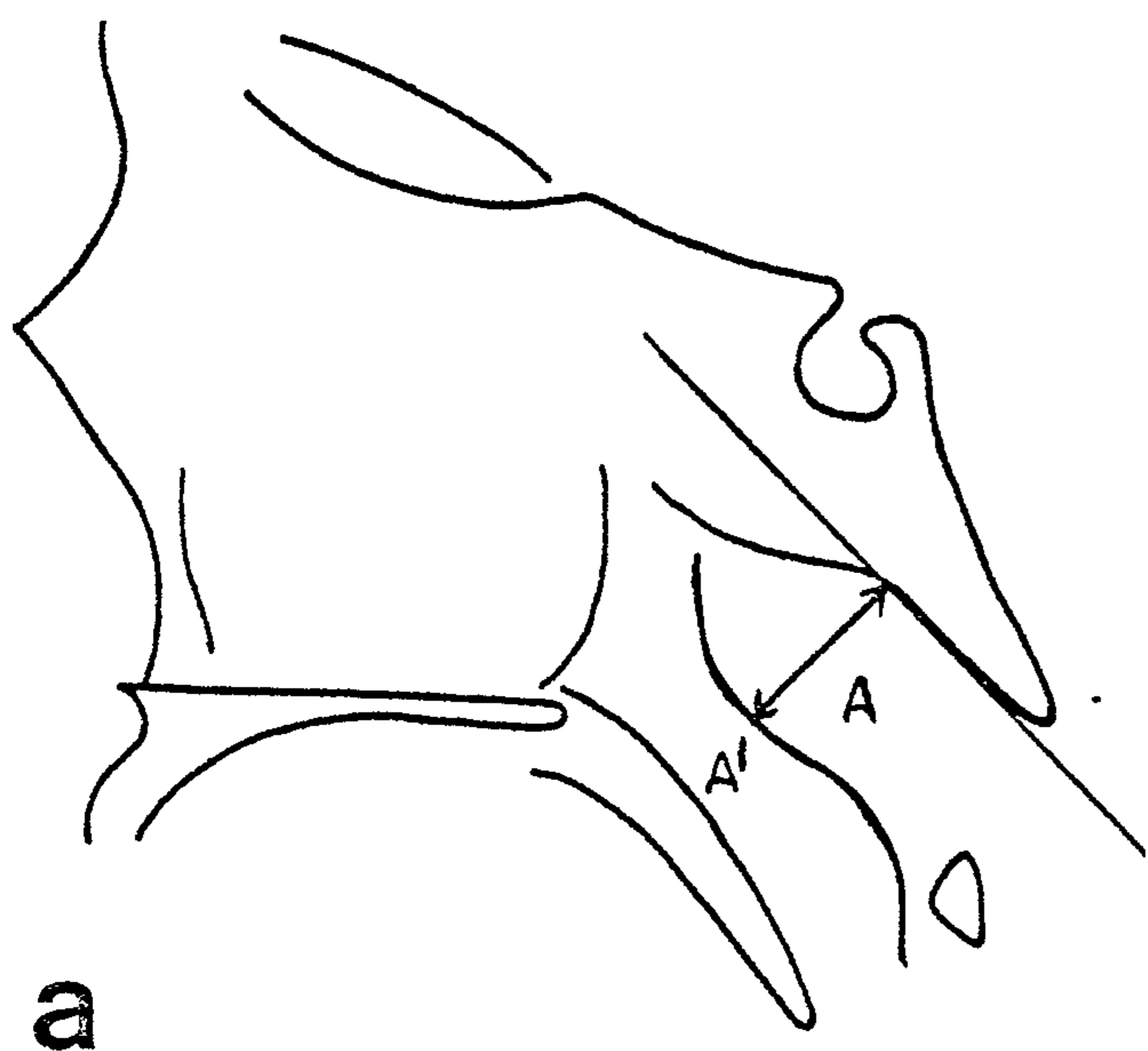


Fig. 39a. Adenoidal measurements

Fig. 39b. nasopharyngeal measurements

(From Fujioka, Young and Girdany 1979)

The adenoidal measurement (A) is the distance on the projection from a point of maximal convexity (A') along inferior margin of adenoid shadow to a line tangent to anterior margin of basiocciput. The nasopharyngeal measurement (N) is the linear distance between posterior superior edge of hard palate (C') and sphenoid-occipital synchondrosis (D').

The AN ratio is obtained by dividing the measurement for A by the value for N.

After examining 1,398 children, means of AN ratios for children of

age 1 to 16 years were obtained. A further 92 patients were selected to compare clinically asserted 'large adenoids' or 'narrow air space' and it was found that a value of AN ratio higher than 0.80 could be considered indicative of large adenoids.

In an exercise to test the correlation between various existing quantifying techniques and the mode of breathing, Schulhof (1979), and Poole, Engel, Chaconas and Encino (1980) found eight measurements to be significant at 0.05 level. All but one are angular or linear parameters (Fig. 40).

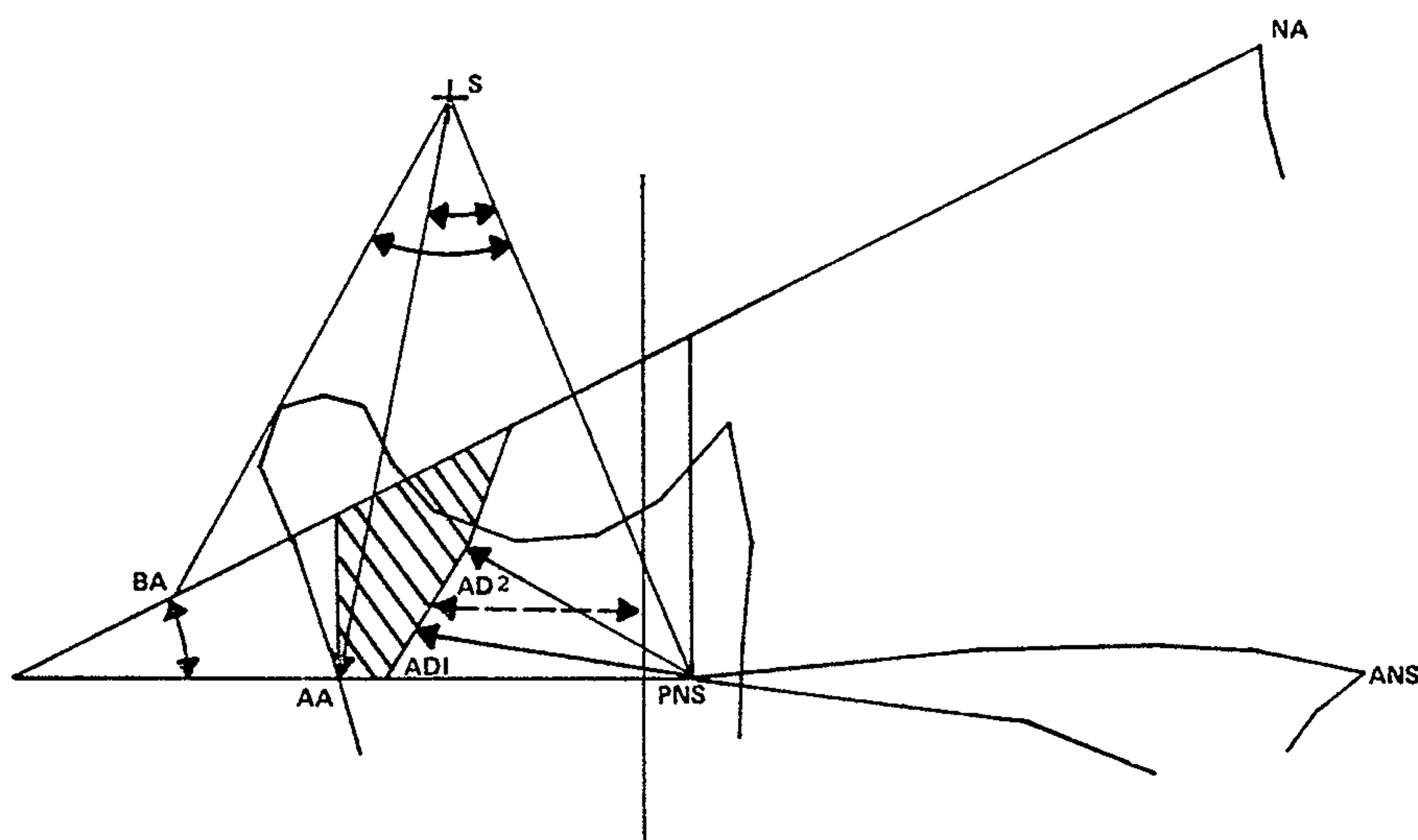


Fig. 40. Significant nasopharyngeal cephalometrics
(From Schulhof 1979)

- (1) *Airway Percentage* : Percentage of nasopharynx occupied by adenoid tissue (Handelman and Osborne 1976).
- (2) *D-AD₁:PNS* : Distance from PNS to nearest adenoid tissue measured along the line PNS-BA (adapted from Linder-Aronson 1970).
- (3) *D-AD₂:PNS* : Distance from PNS to nearest adenoid tissue measured along a line through PNS perpendicular to S-BA (modified from Linder-Aronson and Henrikson 1973).
- (4) *D-PTV:AD* : Distance to nearest adenoid tissue from a point on PTV 5 mm above PNS (Ricketts 1954).
- (5) *Posterior Height* : The length of the line S-AA (Brader 1957; Engman, Priestestersbach and Moll 1965).
- (6) *0* : The angle formed by the intersection of the lines PNS-ANS and BA-NA (modified from Ricketts 1954).
- (7) *Depth 1* : The angle AA-S-PNS (Brader 1957).
- (8) *Depth 2* : The angle BA-S-PNS (Ricketts 1954; Brader 1957).

The four most significant measurements (1-4) were selected to comprise a system to indicate possibilities of abnormal breathing patterns.

4.5 AREAL MEASUREMENTS

Theoretically, areal nasopharyngeal measurements on a radiograph should give a more realistic picture of a region essentially three-dimensional. If nasopharyngeal quantifications were, on the other hand, designed merely as a statistical tool to test hypotheses or to predict tendencies without regard to their own validities, the unit of measurement must be taken *bona fide*.

In fact, it has been proven time and again that linear measurements of radiographic nasopharynx are sufficiently reliable for their purposes (Linder-Aronson and Henrikson 1973). Areal nasopharyngeal radiographic quantifications are, understandably, not extensively used.

Cephalometric areal measurements were made as early as 1948 when Tirk used planimetry to study the growth of the head. Brader (1957), in addition to the linear and angular measurements he made (see previous section), also used a polar compensating planimeter to measure nasopharynx on a radiograph to the nearest 0.01 square inch (Fig. 41).

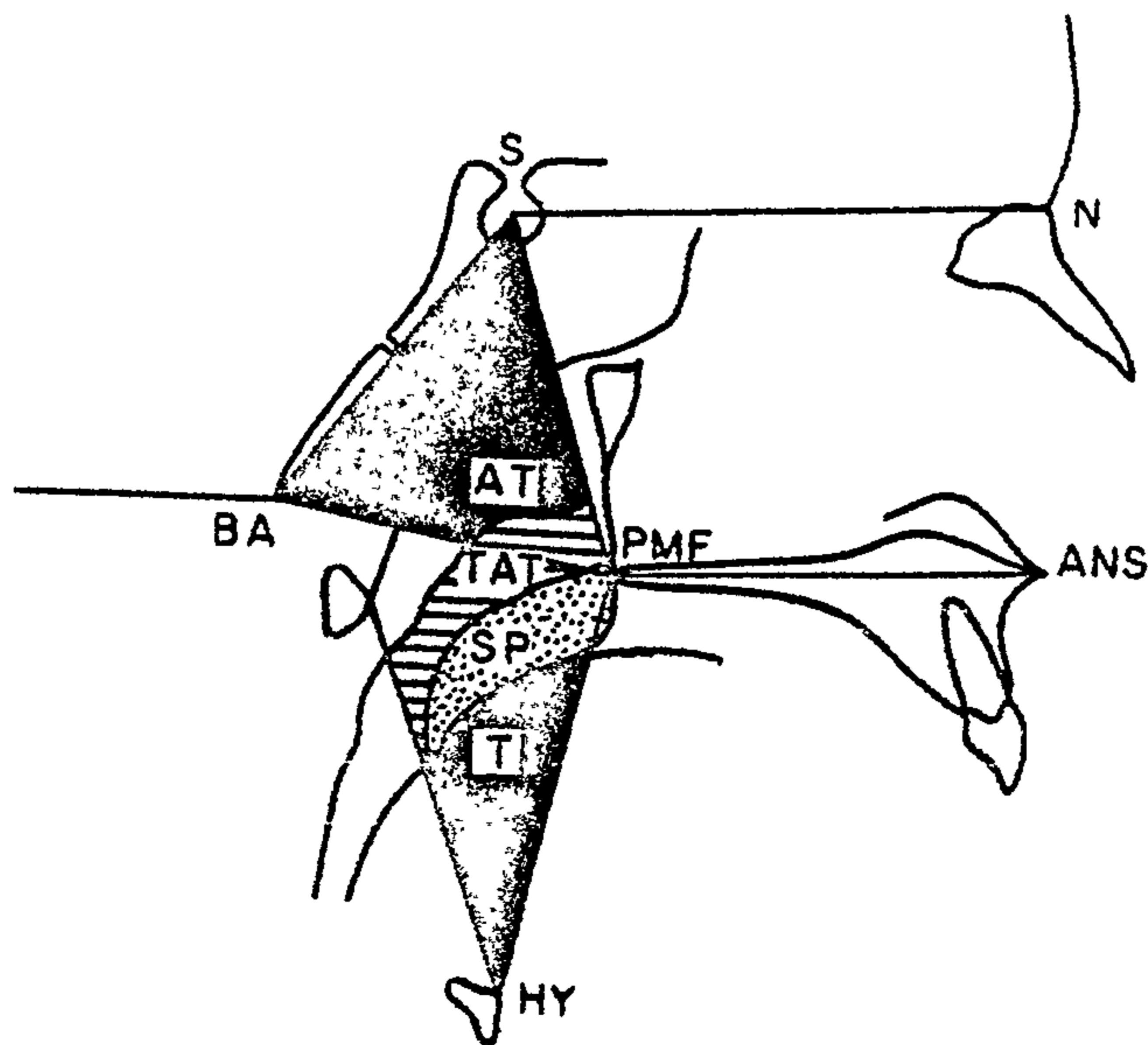


Fig. 41. Areal nasopharyngeal measurements
(From Brader 1957)

S-BA-PMF: indication of size of nasopharyngeal area.

S-BA-AT: indication of quantity of adenoid tissue.

$\frac{S-BA-AT}{S-BA-PMF} \times 100\%$: percentage of adenoid tissue occupying nasopharynx.

On a similar basis, Linder-Aronson (1970) employed areal measurements to give nasopharyngeal variables in his study. Again a planimeter was used, giving both bony and soft tissue nasopharyngeal measurements (Fig. 42).

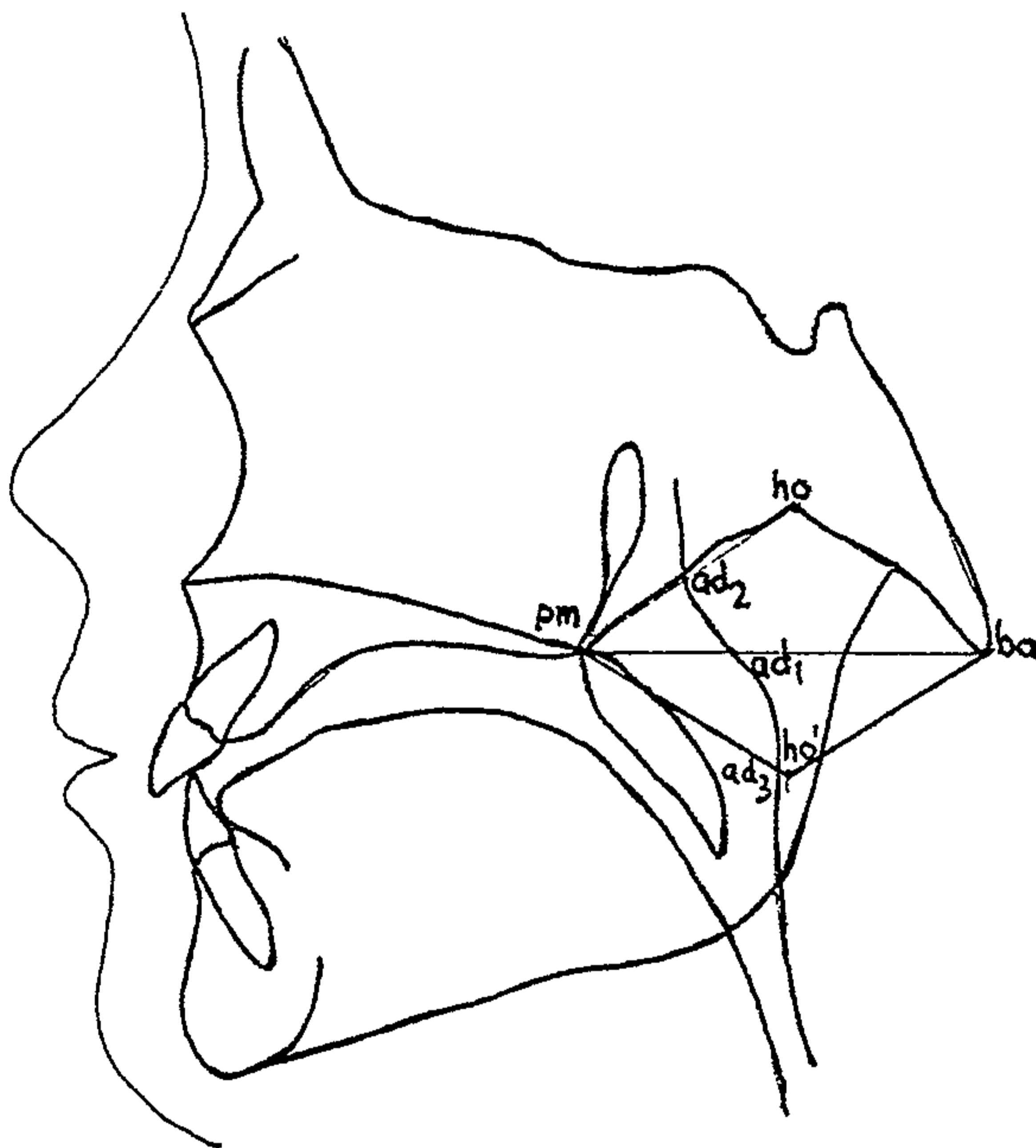


Fig. 42. Areal nasopharyngeal measurements by Linder-Aronson (Adapted from Holmberg and Linder-Aronson 1979)

$\frac{ho}{pm-ba} \times pm-ba \times \frac{1}{2}$: area of nasopharynx (i.e., area bound by pm-ho-ba-pm).

area pm-ho-ba-ho'-pm: area of soft tissue nasopharynx.

ho' is the point corresponding to the point ho on the opposite side of the line pm-ba.

$\frac{ho-ad_2-ad_1-ba}{pm-ho-ba-pm} \times 100\%$: relationship between area of adenoids and area of bony nasopharynx.

$\frac{ad_2-ho-ba-ad_3-ad_1-ad_2}{pm-ho-ba-ho'-pm} \times 100\%$: relationship between area of adenoids and area of soft tissue nasopharynx.

ad₃ is the intersection of the line ba-ho' and the posterior pharyngeal wall.

A slight modification of the Linder-Aronson (1970) method was brought about subsequently (Linder-Aronson and Henrikson 1973; Henrikson, Linder-Aronson and Westborg 1975) and a different areal dimension has been in use since (Fig. 43).

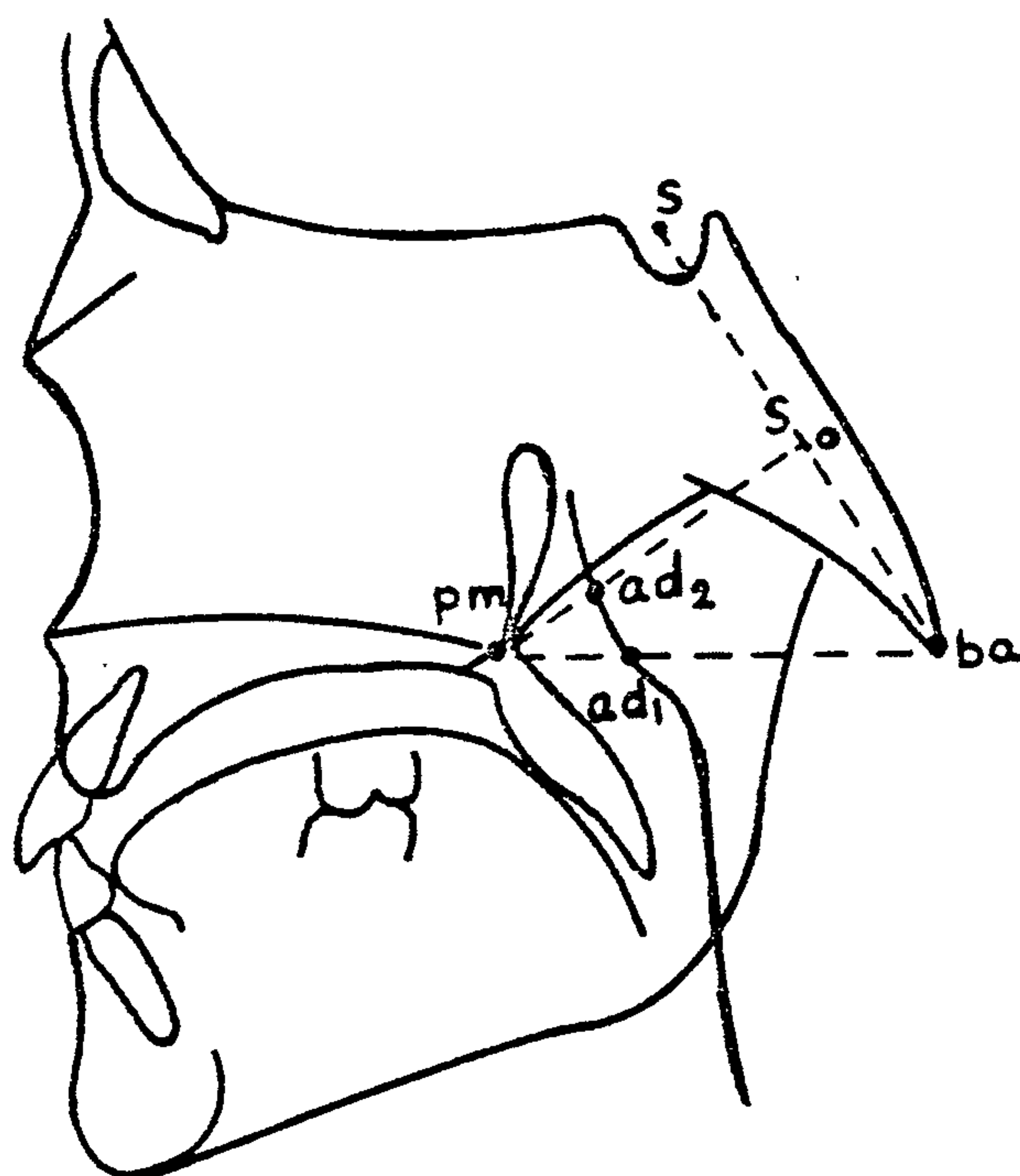


Fig. 43. Areal nasopharyngeal measurements by Henrikson (From Henrikson et al 1975)

Area of airway: pm-ad₁-ad₂-pm measured by planimetry, where S₀ is the mid-point on line S-ba.

Mergen and Jacobs (1970) produced a variation of the boundaries accepted by Brader (1957) and Wildman (1961) to delineate the nasopharynx, and used planimetry to measure the midsagittal area occupied by the air space within the reference points sella, PNS and posterior pharyngeal wall. Also the area of concavity or convexity was evaluated (Fig. 44).

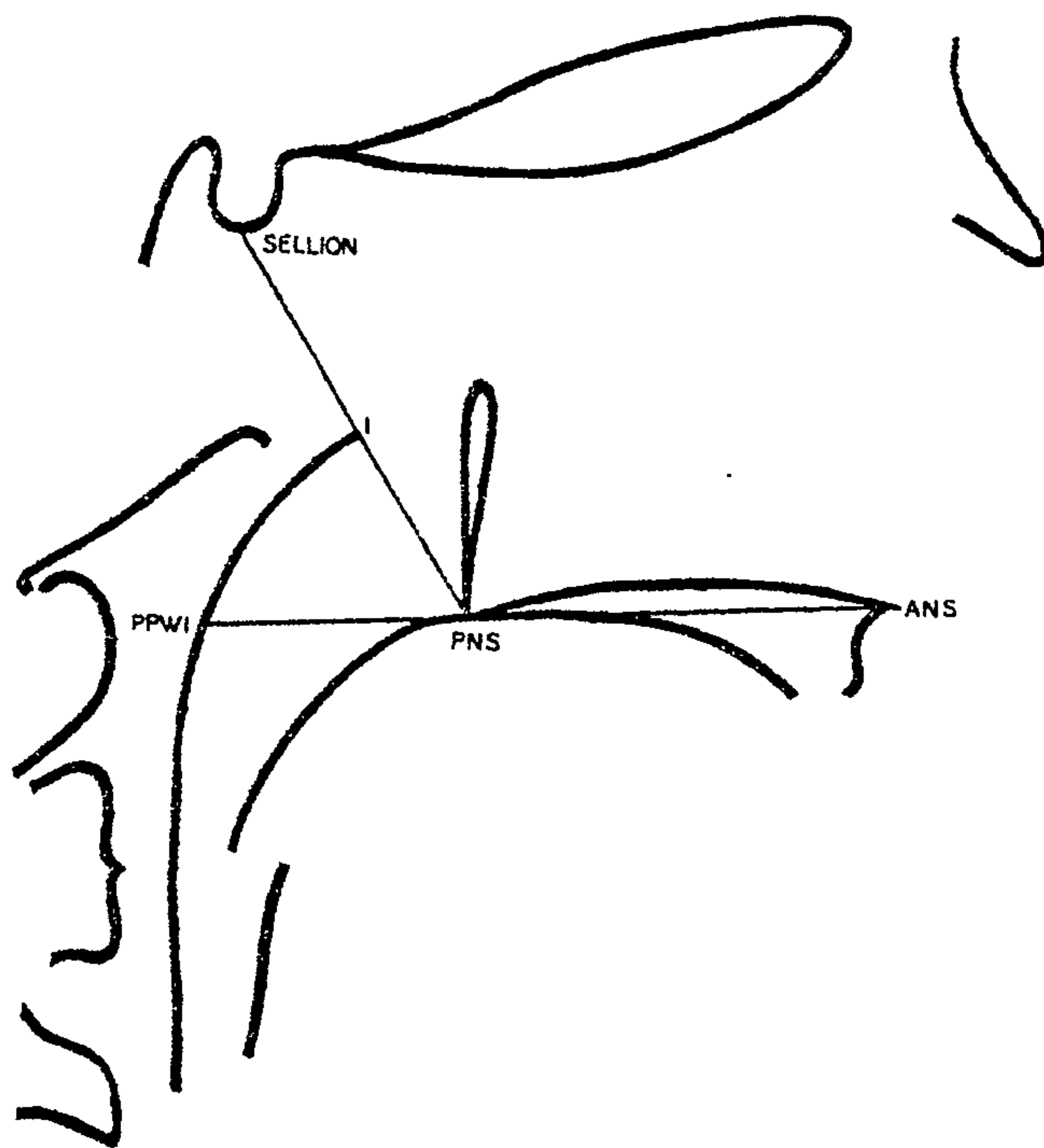


Fig. 44. Area1 nasopharyngeal measurements by Mergen
(From Mergen and Jacobs 1970)

Area I-PPWI-PNS: midsagittal nasopharyngeal area, where
ANS: anterior nasal spine;
PNS: posterior nasal spine;
PPWI: posterior pharyngeal wall intersection;
I: intersection of pharyngeal wall with PNS-sellion line.
The area of concavity or convexity is measured as bounded by
posterior pharyngeal wall and line I-PPWI.

No attempt was made by the authors to related the above measurements to the extent of nasal obstruction or mouth breathing, though it was reported that the midsagittal nasopharyngeal area thus measured was significantly larger in subjects with normal occlusion than those with Class II malocclusion.

On the contrary, values for airway percentages used in the trapezoid analysis of Handelman and Osborne (1976) shown in Fig. 45 were found to correlate highly with incidence of mouth breathing (Schulhof 1979), besides being applied by Preston (1979) in a study on preliterate environment and the nasopharynx.

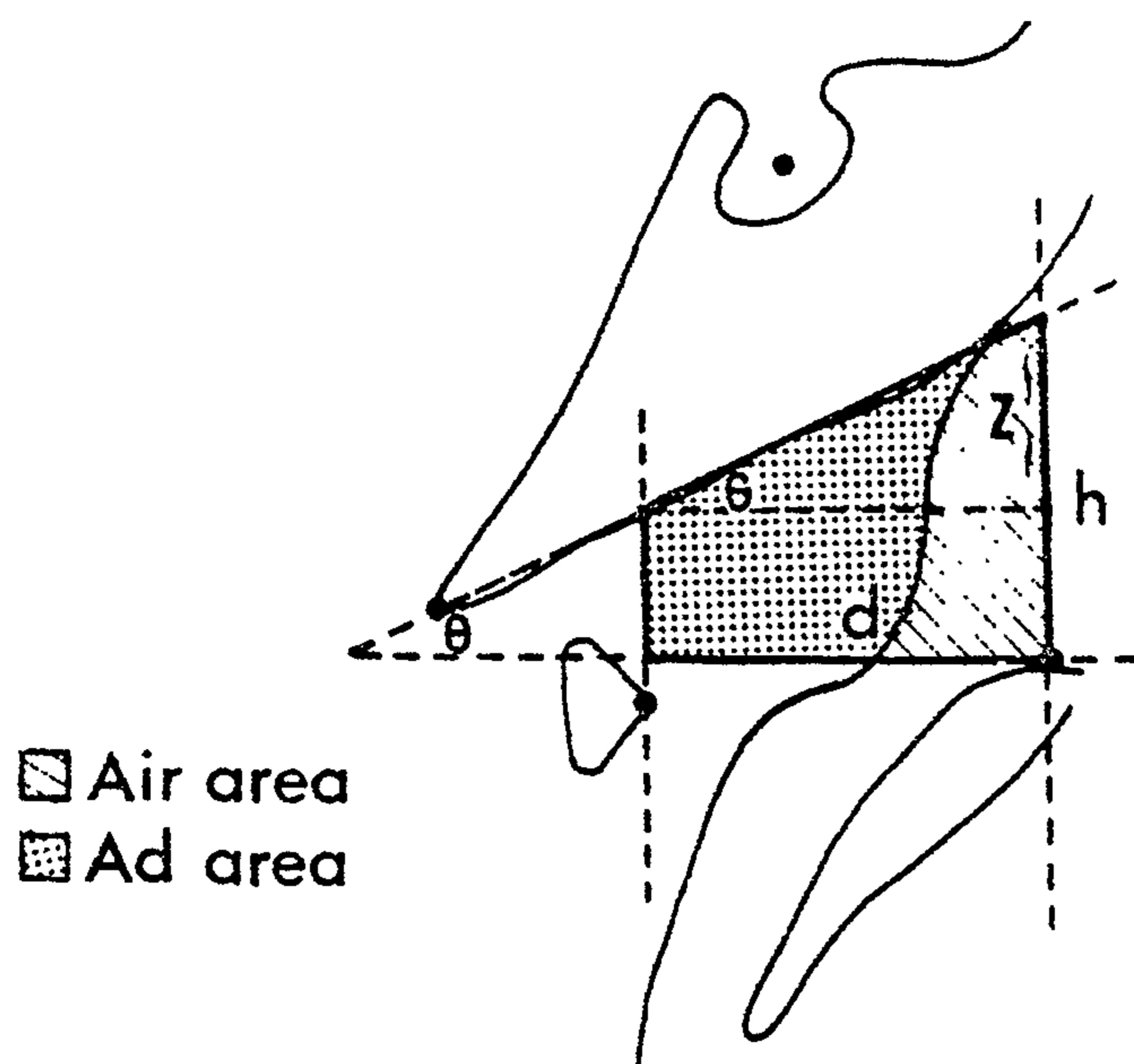


Fig. 45. Areal trapezoid analysis of Handelman
(From Handelman and Osborne 1976)

Nasopharyngeal area is mathematically derived as

$$Np \text{ area} = d \frac{(h - d \tan \theta)}{2}$$
and the airway or adenoid percentages expressed by dividing the respective air area or adenoid area by Np area.

Horowitz, Graf-Pinthus, Bettex, Vinkka and Gerstman (1976), in a factor analysis of craniofacial morphology in cleft lip and palate subjects, quantified bony nasopharynx as an area bound by the cranial base, pterygomaxillary fissure and basion (Fig. 46).

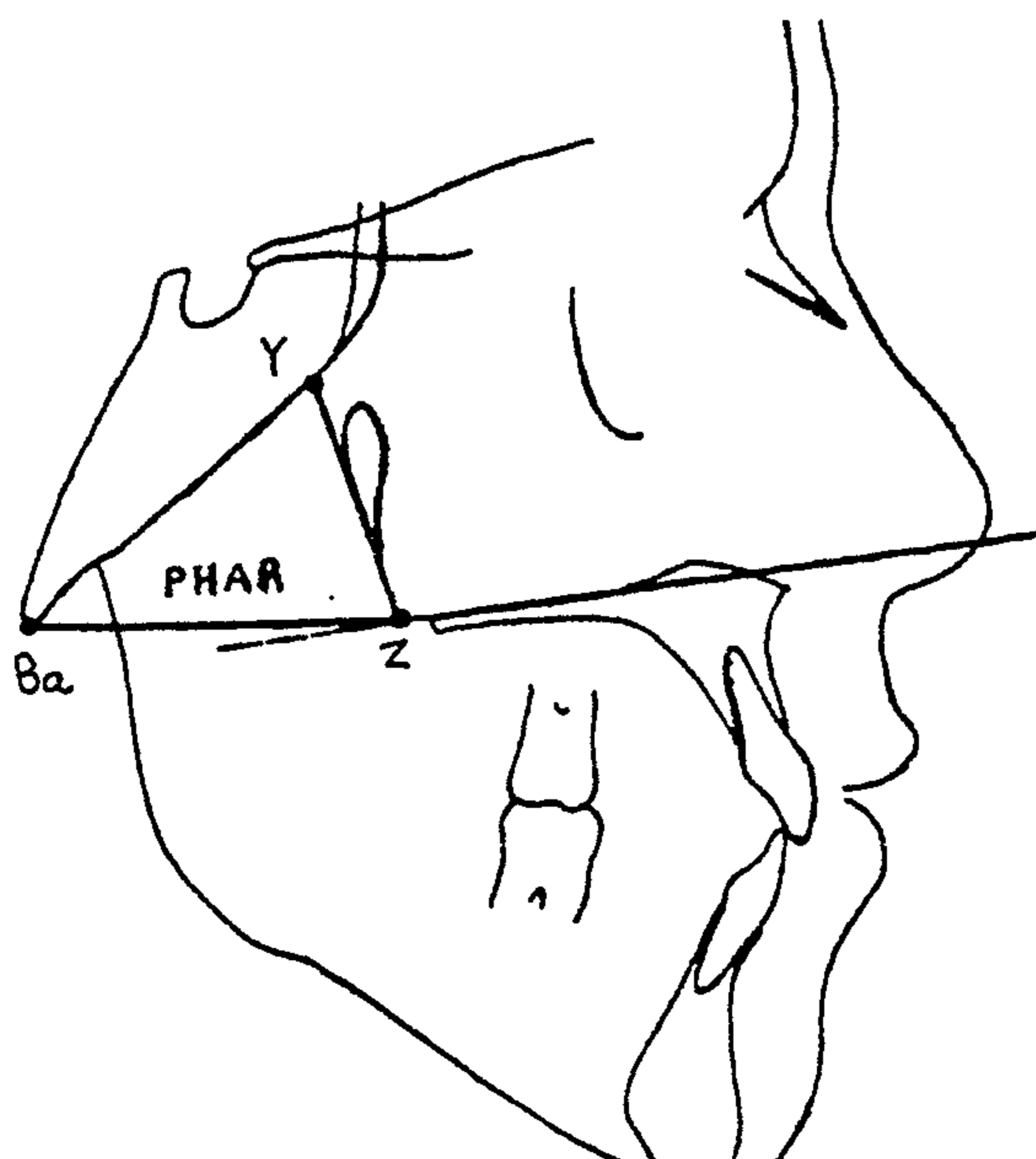


Fig. 46. Bony nasopharynx used by Horowitz
(From Horowitz et al 1976)

Bony nasopharynx (PHAR) is expressed by the area in the triangle y, z, Ba , where

y is the point of intersection of the pharyngeal outline of the clivus and a line tangent to the posterior outline of the pterygomaxillary fissure;

z is the point of intersection of a line tangent to the posterior outline of the pterygomaxillary fissure and the palatal plane;

ba is basion.

The posterior delineation in the foregoing method extends to that of Bergland (1963), and Linder-Aronson (1970), as drawn on lateral cephalometric radiographs. Its validity as an indicator of nasopharyngeal capacity has not been tested and remains doubtful, though its use as a co-variable to describe craniofacial skeletal features cannot be disputed.

Hibbert and Whitehouse (1978) used graph paper tracings to measure area of adenoid instead of planimetry and found it satisfactory (Fig. 47).

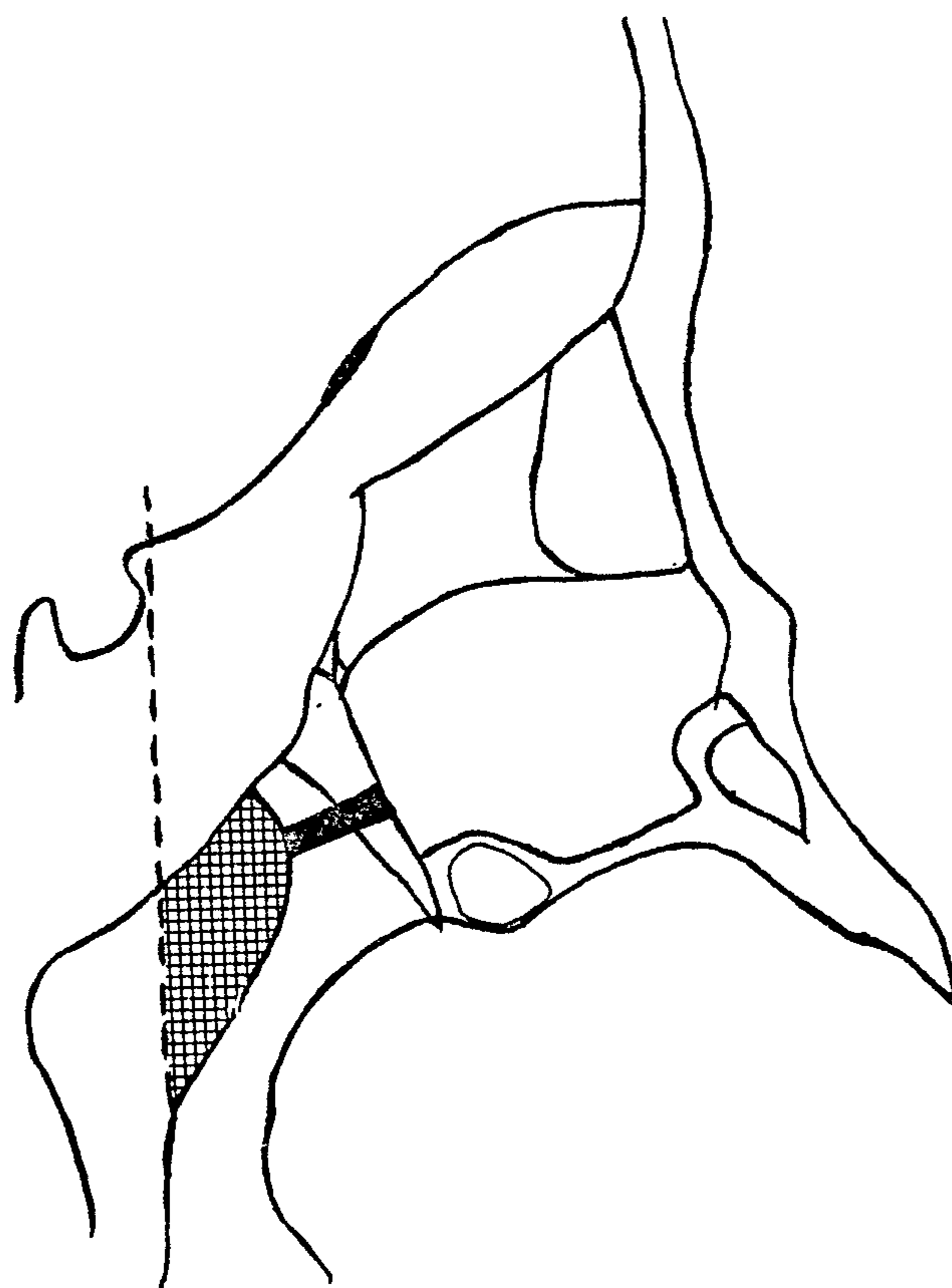


Fig. 47. Areal adenoidal measurement
(From Hibbert and Whitehouse 1978)

The boundary of posterior pharyngeal wall is extrapolated upwards in a straight line, passing close to the anterior wall of pituitary fossa. The area between this line, the margin of the adenoids, and the base of the skull is the adenoid area.

In this case, an attempt to test the validity of the method was made. The authors showed a good correlation between the preoperative assessment of adenoid size so evaluated and the weights of corresponding adenoids removed at surgery in a study consisted of 76 children.

4.6 VOLUMETRIC EVALUATIONS

Volumetric evaluations of the nasopharynx are uncommon because:

- (1) More than one radiograph, often tomograms, is needed (Maran et al 1971).
- (2) It is difficult to separate air and soft tissues on a frontal radiograph (Handelman and Osborne 1976).
- (3) Measurements obtained from a single lateral radiograph have been proven sufficiently useful (Schulhof 1979).

Notwithstanding the above, Bergland (1963) was able to define bony nasopharyngeal volume combining measurements from a lateral skull radiograph and frontal radiograph.

*Capacity of the bony nasopharynx = $\frac{sta-ba \times choanal\ width \times \frac{1}{2}}{sta-ba \times ba}$, where sta : staphylion
 ba : basion
 $choanal\ width$: the greatest distance between the medial pterygoid plates, and is an approximate expression of the width of the bony nasopharynx.*

Similarly, Linder-Aronson (1970) assessed nasopharyngeal bony volume as the sagittal area of bony nasopharynx on a lateral cephalometric radiograph multiplied by the width of posterior choanal aperture registered on a postero-anterior radiograph with the head rotated in a forward direction registering the Frankfort Plane at 26 degrees to horizontal.

*Volume of bony nasopharynx = $\frac{beh-bch \times ho}{pm-ba \times pm-ba \times \frac{1}{2}}$, where ho : hormion
 pm : pterygomaxillare*

ba: basion
choanal width: bch-beh, the most lateral points on the lateral walls of the nasal cavity.

Tomograms were effectively used by Maran et al (1971) in their analysis of nasopharynx. They adopted the principles of solid geometry incorporating the trapezium rule in computing the volume (Fig. 48). This involves dividing the nasopharynx on the lateral cephalometric radiograph into four equal portions by the use of at least five ordinates. The area under the curve is then expressed as: $\frac{1}{2} d (y_1 + 2y_2 + 2y_3 + 2y_4 + y_5)$.

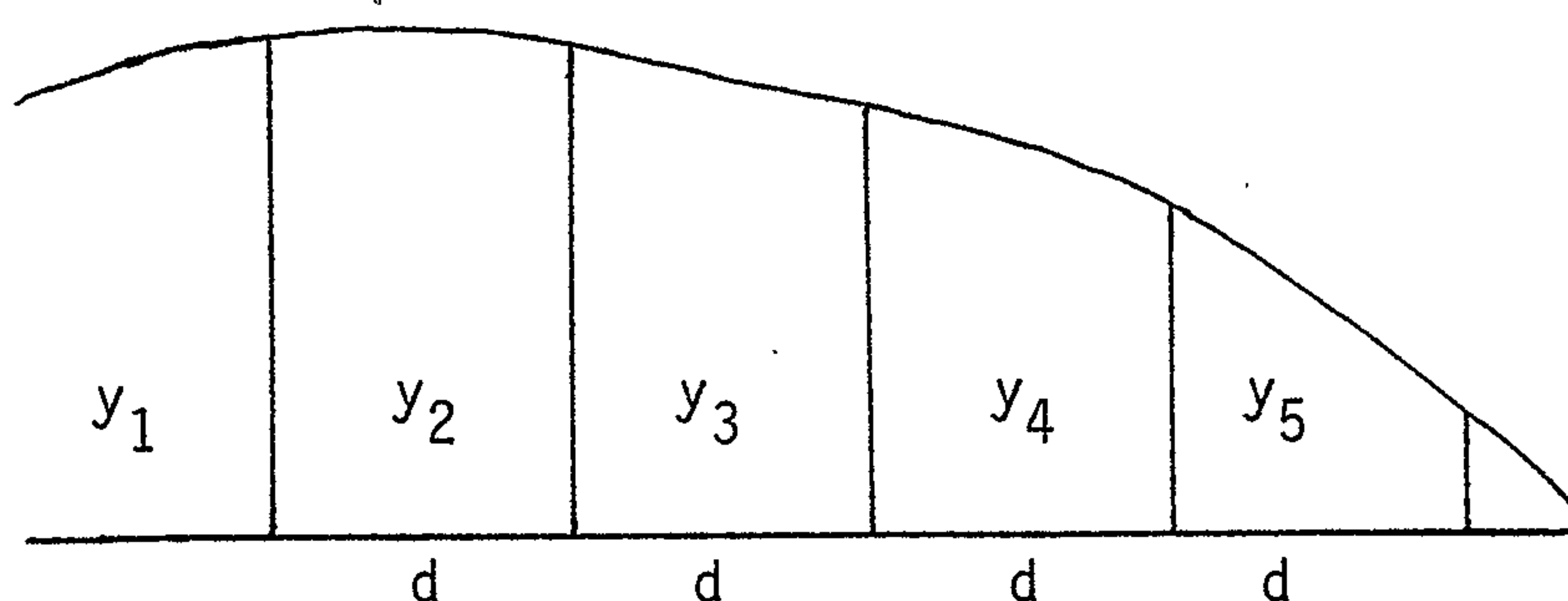


Fig. 48. The trapezium rule to assess volume
 (From Maran et al 1971)

Tomograms were taken to cover the entire region, and the average area derived. This result, when multiplied by the breadth of the nasopharynx, expressed by the distance between the two medial pterygoid plates, would give the volume of the nasopharyngeal prism.

Computed tomography has been proven useful to evaluate volumes of body spaces and was used by Montgomery, Vig, Staab and Matteson (1979) to study the nasal airway, though its use on nasopharyngeal space is still unpublished to date. This method of assessment will be reviewed separately.

4.7 CONCLUSION

Most of the quantifying methods reviewed proved to be valuable as an

inferential tool. Measurements are made either using bony landmarks only (to identify bony nasopharynx), or a combination of bony and soft tissue boundaries (to identify adenoids or airway).

Only one study (Hibbert and Whitehouse 1978) provided direct evidence to justify the validity of the data obtained. Others, at most, compared radiographic measurements with clinical assessments (Devgan and Leach 1979; Fujioka et al 1979). The majority of researchers simply ignored the necessity for substantiation.

When evaluating bony nasopharynx, it is nevertheless logical to assert that methods employing reference points approximating anatomical delineations of the region (Handelman and Osborne 1976) are more valid as indicators than those otherwise (Brader 1957).

In the case of computing soft tissue nasopharyngeal space, the methods using linear measurements passing through points of maximum concavity or convexity (Maran et al 1971), and areal measurements including extremities of the region (Mergen and Jacobs 1970; Castelli, Ramirez and Nasjleti 1973) must be relatively realistic.

Similarly, linear measurements directed towards maximum thickness of adenoids (Ricketts 1954; Mergen and Jacobs 1970; Maran et al 1971; Linder-Aronson 1973b; Castelli, Ramirez and Nasiletj 1973; et al) should give values approaching the actual volumes.

It is also reasonable to judge that areal measurements should portray a closer estimation of the essentially three-dimensional nasopharynx.

Though the soft tissue nasopharynx extends inferiorly to the tip of soft palate, most quantifying methods confined themselves to the portion above the palatal plane. While Subtelny (Ms 1956) suggested the employment of soft tissue boundaries to study nasopharyngeal region, exact quantification was not attempted.