LOGAN TURNER'S

# Diseases of the Nose, Throat, and Ear

SIXTH EDITION

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Edited by

*John P. Stewart*

Assisted by

*R. B. Lumsden*

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# DISEASES OF THE NOSE, THROAT, AND EAR

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# DISEASES OF THE
# NOSE, THROAT, AND EAR

EDITED BY
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ASSISTED BY
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WITH THE COLLABORATION OF
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SIXTH EDITION. COMPLETELY REVISED
249 ILLUSTRATIONS AND 14 COLOURED PLATES

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THIS WORK IS DEDICATED

TO

THE MEMORY

OF

ARTHUR LOGAN TURNER

M.D., LL.D., F.R.C.S.E.

AND THOSE CONTRIBUTORS TO THE PREVIOUS EDITIONS

WHO HAVE SINCE DIED

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# PREFACE TO THE SIXTH EDITION

A SIXTH edition has been called for and some changes have inevitably taken place since the publication of the last edition in 1952. Douglas Guthrie, the remaining survivor of the authors of the 1924 enlarged edition of the original text-book by W. G. Porter, has now ceased to be editor. I have been honoured by my colleagues in becoming the editor of this further edition and R. B. Lumsden has been appointed as the assistant editor.

The subject matter has been brought up to date, some parts entirely re-written, and several new illustrations introduced. The section on Peroral Endoscopy by the late C. E. Scott has been taken over by I. Malcolm Farquharson, while the section on Affections of the Paranasal Sinuses is now G. D. McDowall's responsibility.

Amongst new material incorporated is stapes mobilization, tympanoplasty, and the ultrasound treatment of Ménière's disease, and a short chapter on Facial Paralysis has been added. The modern treatment of malignant disease of the larynx and ear has been elaborated.

The section on the sulpha drugs and the antibiotics has been discontinued as it was felt that with the rapid changes in the use of the latter substances much became obsolete in a very short space of time, and the presentation of the antibiotics throughout the text was thought to be adequate.

The list of prescriptions has been re-introduced for ready reference.

The authors are greatly indebted to M. Lederman of the Royal Marsden Hospital, London, for his valuable contribution on the radiotherapy of malignant disease of the ear.

Lastly they pay tribute to the publishers for their never-failing courtesy and kindness.

JOHN P. STEWART

*Edinburgh,*
*May*, 1961

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# DISEASES OF THE NOSE, THROAT, AND EAR

## *Section I*

## DISEASES OF THE NOSE

A. BROWNLIE SMITH

### *CHAPTER I*

### ANATOMY

#### THE EXTERNAL NOSE, THE NASAL CAVITY, THE NASOPHARYNX, AND THE PARANASAL SINUSES

#### I. THE EXTERNAL NOSE

SHAPED as a triangular pyramid, the external nose has its *root* above and its *base* directed downwards, the latter being perforated by two elliptical orifices, the *nares* or nostrils, separated from one another by a median septum. The free angle of the pyramid is the *apex*; the anterior border joining the root and apex is the *dorsum*, while the upper part of the dorsum, supported by the nasal bones, is termed the *bridge*. Each side of the nose forms an open angle with the cheek and ends below in a rounded eminence, the *ala nasi*, the free edge of which forms the lateral boundary of the corresponding nostril. Over the apex of the nose, the skin is thick and adherent and contains many sebaceous glands.

The framework of the external nose is osseous and cartilaginous. The superior bony part is formed by the two *nasal bones* articulating medially, while laterally each is united with the frontal process of the maxilla. Superiorly, the nasal bone is attached to the frontal bone; and inferiorly, the two bones, united to the lateral cartilages, constitute the upper boundary of the anterior bony aperture of the nose which is completed laterally and below by the sharp anterior margins of the frontal processes and bodies of the two maxillæ.

Four paired and one unpaired cartilage take part in the completion of the external nose. The upper or *lateral cartilages*, triangular in shape, lie immediately below the nasal bones and are attached to them and to the maxillæ by fibrous tissue. Medially, the anterosuperior border of the cartilage of the septum is interposed between the lateral cartilages.

Their lower edges are joined by fibrous tissue to the upper margins of the greater alar cartilages (*Figs.* 1–3).

The *lower* (greater) *alar cartilages* encircle the nostrils and assist in maintaining their patency. Each consists of a *medial* and *lateral* part. The two medial parts (septal processes) together form the lowest part of the nasal septum and, being freely movable, constitute what is termed the *septum mobile nasi.* The lateral parts, oval in outline, are attached above and

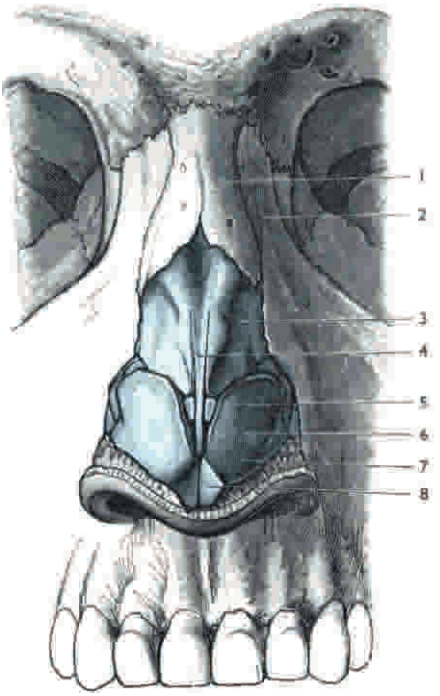


*Fig.* 1.—The external nose. 1, Nasal bone; 2, Frontal process of maxilla; 3, Lateral cartilage; 4, Cartilage of septum; 5, Accessory cartilage; 6, Greater alar cartilage; 7, Lateral crus; 8, Medial crus.

posteriorly to the upper cartilages and to the maxillæ by fibrous tissue, in which two or three *small alar cartilages* are buried. The inferior edge of the lateral part does not reach the free edge of the nostril, the lower part of the ala being devoid of cartilage and composed of subcutaneous fatty and connective tissue.

The *vomeronasal cartilages* constitute the last of the paired cartilages; lying on either side of the postero-inferior edge of the cartilage of the septum they form narrow bands which are attached to the vomer.

The *cartilage of the septum*, as has been indicated, enters into the framework of the external nose. Its anterosuperior border is fixed above to the posterior aspect of the internasal suture and, below this, it is directly continuous with the superior parts of the lower cartilages, which latter may

be regarded as wing-like expansions of the septal cartilage. The antero-inferior border of the septal cartilage is short and is attached by fibrous tissue to the septal processes of the lower alar cartilages. Its anterior angle is rounded and does not reach the apex of the nose.

The chief *muscles* acting upon the external nose are the compressors and dilators of the nostrils and the depressors and elevators of the alæ nasi. They are supplied by the facial nerve. In mouth-breathers the dilators

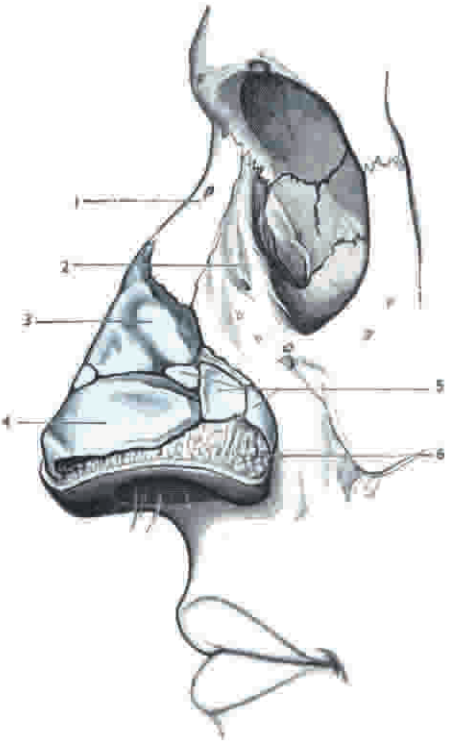


*Fig.* 2.—The external nose. 1, Nasal bone; 2, Frontal process of maxilla; 3, Lateral cartilage; 4, Greater alar cartilage; 5, Lesser alar cartilages; 6, Fatty tissue of ala nasi.

and elevators tend to atrophy from disuse, so that the anterior nares become narrow and slit-like.

The external nose receives its *blood-supply* from the external maxillary (facial) and ophthalmic arteries, while the veins communicate with the anterior facial and ophthalmic veins, the latter being tributaries of the cavernous blood-sinus. The main *lymphatic* vessel follows the course of the anterior facial vein. It receives lymphatics from the anterior part of the nasal mucous membrane and ala nasi, and opens into the submandibular lymph-glands, but other lymph-vessels from the external nose course laterally and communicate with the superficial parotid or pre-auricular lymph-glands.

Through the intercommunication between the mucosal and cutaneous lymphatic network, lupus of the anterior part of the nasal mucous membrane may spread to the alæ nasi and the skin covering the face.

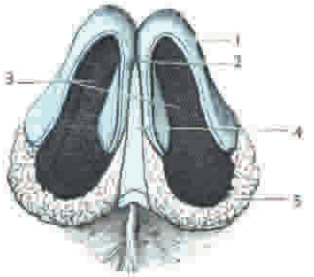


*Fig.* 3.—The external nose. 1, Lateral crus of greater alar cartilage; 2, Medial crus of greater alar cartilage; 3, Nares; 4, Lower edge of cartilage of septum; 5, Fatty tissue of ala nasi.

## II. THE NASAL CAVITY

**The Lateral Wall of the Nasal Cavity.**—The lateral wall of the nasal chamber presents an irregular appearance due to the convoluted arrangement of the three nasal conchæ. The superior and middle conchæ constitute the medial surface of the lateral mass of the ethmoid bone, the *conchæ ethmoidales*, of which they form an integral part (*ethmo-turbinated bones*). The middle concha, which forms an attachment anteriorly with the ethmoidal crest or agger nasi on the medial aspect of the frontal process of the maxilla, projects downwards from the lateral ethmoid mass and thus overhangs and conceals the superior part of the middle meatus. The inferior nasal concha is a separate bone, articulating mainly with the maxilla (*maxillo-turbinated bone*) (*Fig.* 4).

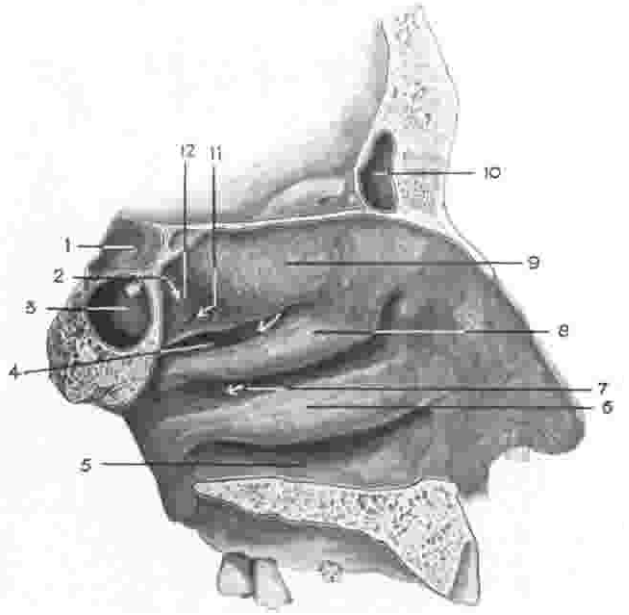


*Fig.* 4.—Lateral wall of left nasal cavity, showing the conchæ or turbinated bodies, the meatuses, and spheno-ethmoidal recess. 1, Right sphenoidal sinus; 2, Sphenoidal ostium; 3, Left sphenoidal sinus; 4, Superior meatus; 5, Inferior meatus; 6, Inferior concha; 7, Accessory ostium of maxillary sinus; 8, Middle concha; 9, Superior concha; 10, Frontal sinus; 11, Ostium of posterior ethmoidal cells; 12, Spheno-ethmoidal recess.

Each nasal concha overhangs a channel or meatus corresponding in length to the concha beneath which it is situated. Thus, the *superior meatus*, with a general direction backwards and downwards, is confined to the posterior third of the lateral wall, its anterior end terminating in a cul-de-sac. The *middle meatus*, commencing at the posterior naris, is directed forwards for about two-thirds of the length of the lateral wall, communicating anteriorly with the *atrium meatus nasi*, a slightly depressed area immediately above the nasal vestibule. One or more accessory ostia of the maxillary sinus may be seen occasionally in the posterior part of the middle meatus (*Fig.* 4).

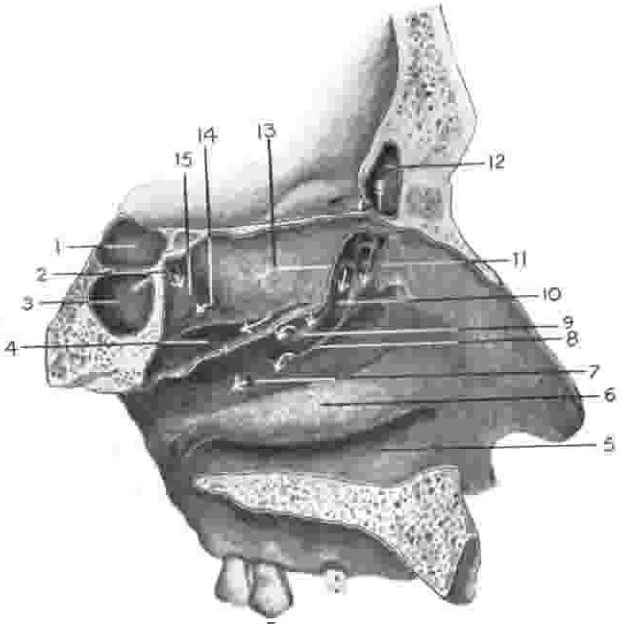


*Fig.* 5.—Lateral wall of left nasal cavity with the middle concha removed along the line ndicated by + ; the lateral wall of the middle meatus is exposed, and the position of the ostia of the sinuses is indicated by arrows. 1, Right sphenoidal sinus ; 2, Sphenoidal ostium ; 3, Left sphenoidal sinus ; 4, Superior meatus ; 5, Inferior meatus ; 6, Inferior concha ; 7, Accessory ostium of maxillary sinus ; 8, Uncinate process ; 9, Ethmoidal bulla ; 10, Infundibulum or semilunar groove ; 11, Nasofrontal duct ; 12, Left frontal sinus ; 13, Superior concha ; 14, Ostium of posterior ethmoidal cells ; 15, Spheno-ethmoidal recess.

The *inferior meatus*, corresponding to the floor of the nasal cavity, extends from the anterior to the posterior aperture of the nose. A fourth and very small meatus may lie above and parallel to the superior meatus as a groove in the lateral wall of the *spheno-ethmoidal recess*. This recess is a shallow but well-defined hollow between the posterior end of the superior concha and the anterior aspect of the body of the sphenoid bone. The space or cleft intervening between the medial surfaces of the conchæ and the septum of the nose, and extending from the roof to the floor of the nasal cavity, is named the *common meatus*. The portion of it which intervenes between the ethmoidal conchæ and the septum is termed the *olfactory sulcus* (*see Fig.* 15).

The superior and middle meatuses derive clinical importance from the fact that the paranasal sinuses communicate with them by means of small ostia. The position of these openings is well seen in *Figs.* 4 and 5. The inferior meatus receives at its anterior end the opening of the *naso-lacrimal canal*, situated under cover of the inferior concha and close to the attachment of that bone to the lateral nasal wall.

As the middle meatus requires closer inspection, the attachment of the middle nasal concha must be divided throughout its entire length and the overhanging portion removed, so as to bring into view the whole surface of the meatus. This has been done in *Fig.* 5. Two prominent structures are thus seen: the convex surface of the bulla cell of the ethmoid

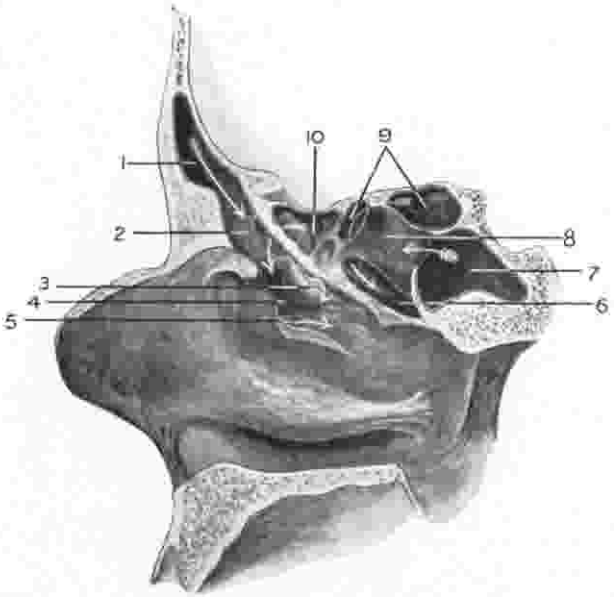


*Fig.* 6.—Lateral wall of right nasal cavity with the superior and middle conchæ removed; the infundibulum and nasofrontal duct are continuous; the uncinate process has been turned down in order to show the maxillary sinus ostium. 1, Right frontal sinus; 2, Nasofrontal duct; 3, Ethmoidal bulla; 4, Infundibulum or semilunar groove; 5, Maxillary ostium; 6, Superior meatus; 7, Right sphenoidal sinus; 8, Spheno-ethmoidal recess; 9, Posterior ethmoidal cells; 10, Anterior ethmoidal cell.

labyrinth (*bulla ethmoidalis*) and, anterior and inferior to it, the well-defined curved free margin of the uncinate process of the ethmoid (*processus uncinatus*). Between these two structures there is a narrow interval, the *semilunar gap* (hiatus semilunaris), which serves as a communication between the middle meatus and a small triangular-shaped channel or gutter, the *semilunar groove* (infundibulum ethmoidale), bounded superiorly by the inferior surface of the bulla, and inferiorly and medially by the lateral surface of the uncinate process. Posteriorly and inferiorly the semilunar groove is closed by a bony lamina connecting the posterior end of the bulla with the uncinate process. The opening of the maxillary sinus communicates with the most inferior part of the infundibulum. Superiorly and anteriorly

the infundibulum may terminate in one of two ways. In about one-half of the heads examined a bony lamina connects the anterior end of the uncinate process with the bulla ; here the semilunar groove receives the opening of an anterior ethmoidal cell. In these cases the frontal sinus opens directly into the middle meatus anterior to the semilunar groove (*Fig.* 5). In the remainder of the heads this channel is continued upwards to the ostium frontale as the *nasofrontal duct* (*Fig.* 6). This duct varies somewhat in its direction and in the calibre of its lumen, consequent upon the irregular development of the ethmoidal cells surrounding it, and, for this reason, access to the frontal sinus by probe or catheter passed from the nasal cavity may become somewhat difficult.

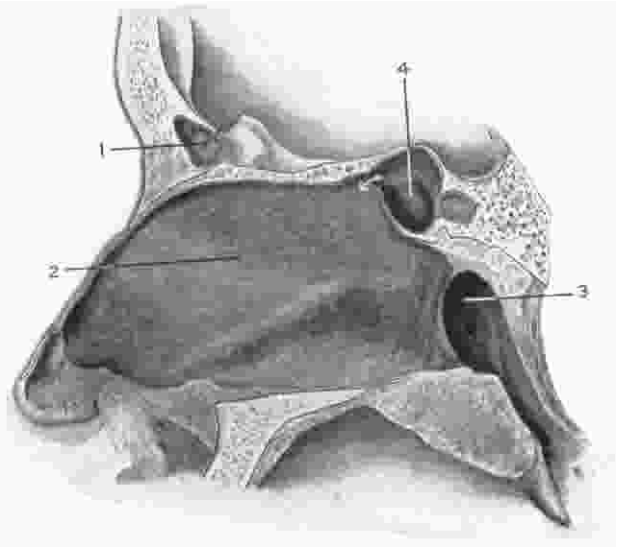


*Fig.* 7.—Left side of the nasal septum, covered with mucous membrane, showing an oblique septal crest at the junction of the vomer with the cartilage of the septum. 1, Left frontal sinus ; 2, Septum of the nose ; 3, Nasopharyngeal cavity ; 4, Left sphenoidal sinus.

**The Septum** or medial wall of the nasal cavity is in part osseous and in part cartilaginous. (*Figs.* 7, 8.) It is formed mainly by the perpendicular plate of the ethmoid superiorly and posteriorly and by the vomer inferiorly and posteriorly, while the septal cartilage, anteriorly, fills in the angular interval between these two bones. The following additional bony processes complete its structure : the nasal spine or frontal bone and the crest of the nasal bones anteriorly and superiorly, the rostrum of the sphenoid posteriorly and, in the median plane inferiorly, the nasal crests of the maxillæ and palatine bones. The cartilage of the septum is strengthened anteriorly by the medial part of the greater alar cartilages, and along its inferior margin by the vomeronasal cartilages. The main arterial supply to the septum nasi is derived from the septal branch of the sphenopalatine artery which courses along the surface of the vomer; it anastomoses at the anterior inferior part of the septum with the greater palatine artery (superior palatine), with the septal branch of the superior

labial (coronary) artery, and with the septal branch of the anterior ethmoidal artery (*Fig.* 8). The site of anastomosis constitutes the 'bleeding area' of the septum.

**The Roof** of the nasal cavity is very narrow save in its posterior part; anteriorly, it is formed by the nasal and frontal bones; in its middle portion by the cribriform plate of the ethmoid bone, which is perforated by the foramina transmitting the branches of the olfactory nerve, the anterior ethmoidal nerve and the ethmoidal vessels; and posteriorly, by the body of the sphenoid bone.

**The Floor** of the nasal cavity, which is shorter and wider than the roof, is nearly horizontal from before backwards, but is slightly concave transversely. Its transverse diameter measures 1 cm.

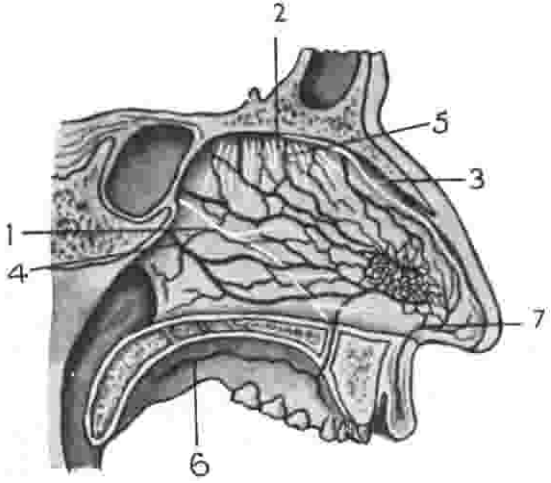


*Fig.* 8.—Right side of the nasal septum, showing the nervous and arterial supply, and the 'bleeding area' of the septum anteriorly and inferiorly. 1, Right long sphenopalatine nerve; 2, Olfactory nerve branches; 3, Medial nasal nerve; 4, Septal posterior nasal artery from sphenopalatine; 5, Anterior and posterior ethmoidal arteries; 6, Great palatine artery; 7, Septal branch of superior labial artery.

The *mucous membrane* of the inferior concha consists of a layer of fairly dense connective tissue containing the larger blood-vessels and some unstriped muscle-fibres; in addition, it contains an erectile tissue layer made up of thin-walled blood-vessels of irregular size and shape; this is better developed at the anterior and posterior ends of the concha and along its inferior border than elsewhere. Along the periosteal aspect of the mucous membrane, and also beneath the epithelial basement membrane, is a layer of elastic fibres with similar fibres running radially between them. The whole constitutes an elastic tissue framework which causes the mucosa to return to its normal size when the vascular engorgement of the erectile tissue has passed off. The surface epithelium is of the columnar ciliated type and beneath it are several layers of cubical cells resting upon the basement membrane. The racemose mucous glands lie beneath the latter, their ducts passing through it and opening upon the surface.

The mucous membrane of the middle concha, while resembling generally that of the inferior, differs in the fact that it does not contain the same amount of erectile tissue, while in general structure it is looser and more delicate.

The *sensory nerve-supply* (*Figs.* 8, 9) of the nasal mucous membrane is furnished mainly by the maxillary division of the trigeminal through the branches arising from the sphenopalatine ganglion (Meckel), which is situated in the superior part of the pterygopalatine fossa in close proximity to the sphenopalatine foramen. "The foramen lies at a point just posterior to and immediately above the posterior tip of the middle concha" (Sluder). The ganglion may be found as close as 1 or 2 mm. to the nasal mucosa, or separated from it at a distance of 9 mm. The anterior portion

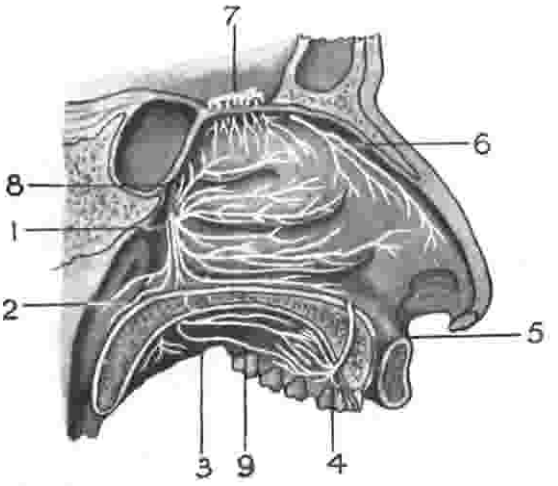


*Fig.* 9.—Innervation of the lateral nasal wall. 1, Sphenopalatine ganglion (Meckel); 2, 3, Lesser palatine nerves; 4, 5, Long sphenopalatine nerve; 6, Lateral internal nasal nerve; 7, Olfactory bulb and nerves; 8, Short sphenopalatine nerves; 9, Greater palatine nerve.

of the lateral wall and of the nasal septum receives its supply from the ophthalmic nerve through its lateral and medial internal nasal branches. The infra-orbital nerve or terminal branch of the maxillary nerve through its anterior dental branch supplies the anterior end of the inferior concha and adjacent nasal floor.

*Secretory nerve-fibres* supplying the various glandular structures and the involuntary muscle tissue belong to the autonomic nervous system. The autonomic nervous system consists of two parts which are anatomically and physiologically distinct—namely (1) the sympathetic and (2) the parasympathetic fibres. The parasympathetic fibres arise in part from the brain stem and in part from the sacral region of the cord, the sympathetic fibres taking origin from the spinal cord alone.

The sympathetic fibres produce vasoconstriction and diminish secretion and are derived from the superior cervical sympathetic ganglion. These

fibres are postganglionic neurones which are carried in the deep petrosal nerve and the nerve of the pterygoid canal or Vidian nerve to the sphenopalatine ganglion, which they traverse before being distributed to the blood-vessels of the nasal mucosa. The parasympathetic fibres produce vasodilatation and increase secretion, and are carried in the great superficial petrosal nerve and the Vidian nerve to the sphenopalatine ganglion, where there is a synapse, and from which postganglionic fibres are distributed. The Vidian nerve thus carries postganglionic sympathetic fibres and preganglionic parasympathetic fibres. The manner by which these reactions of vasoconstriction or dilatation and diminished or increased secretion are brought about by impulses from the nasal mucous membrane itself is not yet clearly understood.

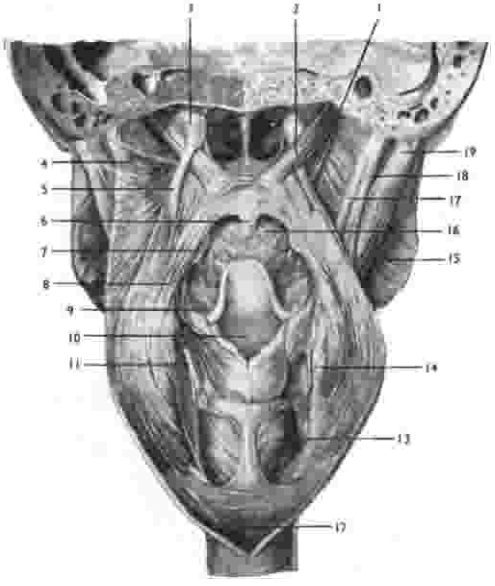


*Fig.* 10.—Dissection of pharynx. 1, Tensor palati; 2, Levator palati; 3, Cartilage of Eustachian tube; 4, Superior constrictor; 5, Salpingopharyngeus; 6, Uvula; 7, Palatine tonsil; 8, Palatopharyngeus; 9, Pharyngo-epiglottic fold; 10, Upper aperture of larynx; 11, Superior laryngeal nerve; 12, Œsophagus; 13, Crico-arytenoideus posticus; 14, Posterior border of thyroid cartilage; 15, Internal pterygoid; 16, Tongue; 17, Stylopharyngeus; 18, Stylohyoid; 19, Digastric.

In Horner's syndrome, due to the disturbance of the cervical sympathetic system, there is vascular dilatation and profuse secretion from the nasal cavity on the affected side, probably because of the uncontrolled action of the dilator (parasympathetic) fibres.

The *olfactory nerves*, some twenty filaments in number, derived from the olfactory bulb lying upon the cribriform plate, enter the nasal cavity through foramina piercing the osseous plate; they are distributed in a network lying in the mucous membrane covering the upper third of the nasal septum, nearly the whole of the opposed medial surface of the superior concha, and a small part of the medial surface of the middle concha anteriorly (*Figs.* 8, 9).

The perineural sheaths of the olfactory nerve filaments — erroneously described as lymph sheaths — communicate directly with the pia-arachnoid spaces. This communication has been demonstrated experimentally in animals and young human subjects by injecting the spaces with coloured material which passed downwards through the cribriform foramina transmitting the olfactory nerves. Conversely, infection of the perineural sheaths from a primary septic focus within the nose has been demonstrated microscopically in patients dying of acute purulent leptomeningitis, following intranasal operations during which the sheaths have been torn. The pus traced upwards within the sheaths has been found directly continuous with the pus in the cerebral membranes.

The olfactory area of the nasal cavity is, therefore, a potential danger zone. This fact should be borne in mind when operating on the ethmoidal cell labyrinth. (*See Fig.* 39, p. 50.)

The *veins* from the walls of the nasal cavity pass for the most part through the sphenopalatine foramen and terminate in the pterygoid plexus, but branches join the superior ophthalmic vein in the orbit, and anteriorly there is intercommunication with the anterior facial vein.

The *lymphatic vessels* of the most anterior part of the nasal mucosa pass forwards and, joining the cutaneous lymphatics of the nasal vestibule, accompany the anterior facial vein and enter the submandibular glands; the efferents of these glands drain into the superior deep cervical glands. The lymphatics from the rest of the nasal mucous membrane pass backwards and, finally, enter the medial superior deep cervical glands, some of them in their course passing through the retro-pharyngeal glands.

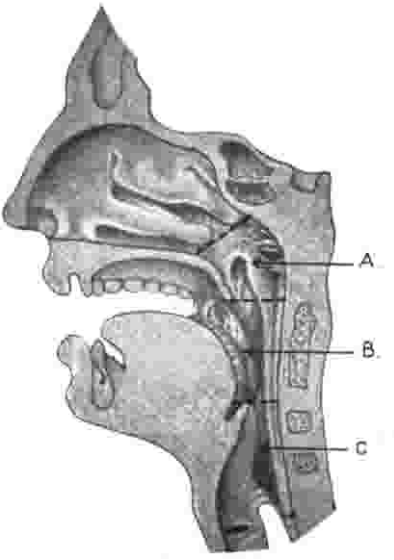


*Fig.* 11.—Anatomical divisions of the pharynx. A, Nasal pharynx (pars nasalis); B, Oral pharynx (pars oralis); C, Laryngeal pharynx (pars laryngea).

### III. THE NASOPHARYNX

The nasopharynx (pars nasalis, *Figs.* 10, 11), with the exception of the floor, which is formed by the soft palate, has rigid and immovable boundaries. The roof, formed by the body of the sphenoid bone and basioccipital, curves downwards and backwards so as to become continuous with the posterior wall; the latter is almost vertical and is formed by the upper cervical vertebræ, clothed by the prevertebral muscles and the mucosa, which is lined for the most part by columnar ciliated epithelium. On the roof and posterior wall in young children lies an aggregation of lymphoid tissue known as the nasopharyngeal tonsil; 'adenoids', so common in childhood, is the name applied to enlargement of this structure (*see Fig.* 84, p. 167). Anteriorly the nasopharynx communicates with the nasal cavities through the posterior apertures of the nose (nares or choanæ) which are separated from each other by the septum nasi. The lateral wall of the nasopharynx is of importance, as here is situated on either side the orifice of the pharyngo-tympanic tube (Eustachian tube). The opening, which is directed downwards, forwards, and medially, presents a funnel-shaped appearance and is bounded superiorly and posteriorly by the salient rounded ridge of the tubal elevation (Eustachian cushion) formed by the projection of the cartilage which partially surrounds the tube. The pharyngeal opening (Eustachian orifice) is situated just superior to the plane of the hard palate. The mucosa lining the tube is directly continuous with that of the nasopharynx, and is likewise covered by ciliated epithelium. It is well supplied

with mucous glands, and in the submucous layer there is, in early life, an aggregation of lymphoid tissue. Immediately posterior to the tubal elevation is a deep depression known as the pharyngeal recess (fossa of Rosenmüller). (*See also* Chapter XIV.)

## IV. THE PARANASAL SINUSES

The paranasal air sinuses, arranged in pairs, are situated in relation to each nasal cavity. They may be appropriately studied, both on anatomical and clinical grounds, as comprising two groups, the anterior and the posterior. The former includes the maxillary sinus (antrum Highmori), the anterior ethmoidal cells, and the frontal sinus, cavities communicating with the middle meatus of the nose under cover of the concha nasalis media (the middle turbinal). The posterior group contains the posterior ethmoidal cells and the sphenoidal sinus, communicating with the superior meatus and with the small spheno-ethmoidal recess on the lateral nasal wall immediately above the meatus.

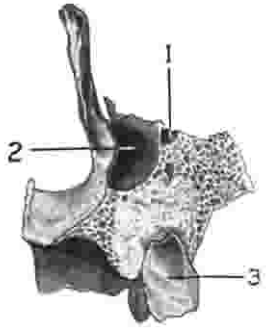


*Fig.* 12.—Coronal section of the right maxilla during the period of the first dentition ; the small maxillary sinus lies medially to the infra-orbital canal ; the maxilla consists largely of cancellous bone. 1, Infra-orbital canal ; 2, Right maxillary sinus ; 3, Second molar tooth.

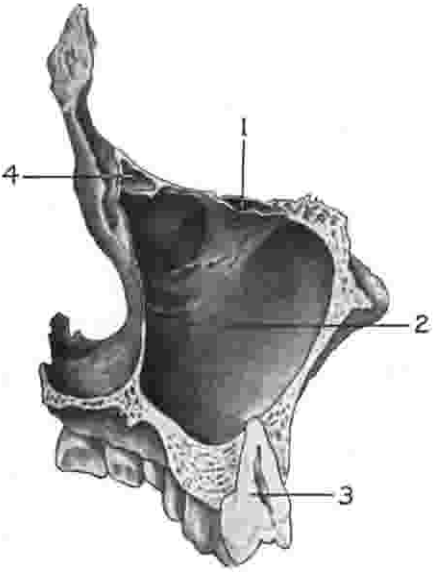


*Fig.* 13.—Coronal section of the right maxilla of an adult, showing the fully developed maxillary sinus. The floor of the sinus is on a lower plane than that of the nasal floor ; the molar fang projects into the cavity of the sinus. 1, Infra-orbital canal ; 2, Right maxillary sinus ; 3, First molar tooth ; 4, Maxillo-ethmoidal cell.

**The Maxillary Sinus.—**

*Development.*—The maxillary sinus is first noticed about the seventeenth day of fœtal life as an invagination of the mucous membrane of the lateral wall of the ethmoid infundibulum. Rarely there may be double pouching, which would result in a double sinus. At birth the sinus exists as a small, but definite cavity. Associated with the enlargement of the maxillary bone by deposition of cancellous osseous tissue between its palatal and orbital surfaces, there is a slowly progressive absorption of the same on the medial nasal aspect of the maxilla. In this way the sinus gradually increases in