THE STRUCTURE OF THE MAMMALIAN ŒSOPHAGUS.

BY

EMIL GOETSCH.
From the Hull Laboratory of Anatomy, University of Chicago.

WITH 17 FIGURES.

One of the most interesting features in the structure of the Mammalian Œsophagus is the extreme variability in the degree of development of the œsophageal glands in different species. For example, according to Ranvier (84) and others, the œsophagus of the rabbit, guinea-pig and rat is wholly devoid of glands, while in the dog, a thick layer of mucous glands nearly filling the submucous coat is found throughout the whole extent of the organ. Nor is this disparity confined to species belonging to different orders, for the cat and dog among carnivora and the sheep and pig among ungulates present equally striking differences in this respect.

The reasons which have been advanced for this disparity are based on the assumption that the function of the œsophageal glands is to furnish a secretion which will serve to lubricate the surface of the œsophageal mucous membrane and so facilitate the passage of the bolus of food in deglutition. Assuming that the secretion of the œsophageal glands possesses this purely mechanical function, the logical conclusion is that their development will be influenced by several factors which determine the consistence of the food-bolus which is to be swallowed, such for example as the character and bulk of the food itself, the efficiency of the masticatory mechanism, and the relative development of the salivary glands furnishing a secretion by means of which the food is diluted and rendered of softer consistence. Accordingly, various attempts have been made to establish a correlation between the degree of development of the salivary glands and the efficiency of the masticatory mechanism on

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the one hand, and the number and size of the œsophageal glands on the other hand. For example, Ranvier (84), speaking of the difference between the rodents and the dog in this respect, remarks that this is easily comprehensible when one remembers that in the rabbit and other rodents the bolus of food is liquid or semi-liquid, and therefore mucous glands are not necessary, that on the other hand the dog swallows greedily solid matters and untriturated bones and hence the glands are indispensable. Renaut (97) similarly calls attention to the difference in masticatory efficiency between the ox and rodents on the one hand and the dog on the other and explains on this basis the differences in the number of œsophageal glands.

Many examples can be found in favor of this explanation. When, however, one attempts to give it a general application, unexpected difficulties arise. For example, there is not a sufficient difference in the development of the salivary glands, of the masticatory mechanism, or in the consistence of the food, to explain adequately the fact that glands are very numerous in the œsophagus of the dog and wholly absent from that of the cat.

The possibility that the mechanical function of the œsophageal glands may be a purely subsidiary one, and that their true function may be something quite different from this, has received but little attention at the hands of the investigators. Rubeli (90), it is true, suggested that the secretion might be of use in digestion, but his suggestion was based not on experimental data derived from mammals but on the observations of Decker (87), Swieçicki (76), Langley (79), etc., on the formation of proteolytic enzymes in the œsophagus of fishes and batrachians. As will appear later, these observations deal with structures which are not homologous with the œsophageal glands of mammals and can therefore not be used to draw conclusions concerning the function of the mammalian œsophageal glands. In this connection a question of much importance which has been variously answered by different observers is whether the œsophageal glands of mammals are pure mucous glands, or mixed glands containing serous demilunes. If serous cells are present, then one must at once think of a chemical function of the œsophageal secretion as well as a mechanical one. Klein (79) asserts that

demilunes occur in the œsophageal glands of the dog. Renaut (97) describing the œsophageal glands of the dog and of man makes the statement that they may be seen in preparations stained with his glycerine-hæmatoxylin-eosin mixture, without specifying whether he found them in one or both species. Schaffer (97) denies their presence in the human œsophageal glands and Rubeli (90) failed to find them in a number of domestic mammals. Stöhr (87) appears to have seen demilunes in his preparations, but to have interpreted them in accord with his well-known phase-theory as inactive mucous cells. More recently Helm (67) has described typical demilunes in the dog and pig and has demonstrated in them, by means of the iron-hæmatoxylin method, the intercellular secretion canaliculi.

Assuming that the function of the secretion of these glands is in part at least that of mechanically aiding deglutition, one would expect that in those cases where the character of the food and the nature of mastication suggest the need of these structures, but where, notwithstanding, no œsophageal glands are present, a compensatory development of other structures will be found, as, for example, a thickening of the stratified epithelium or an increased development of the muscularis mucosæ or of the external muscular coat. In other words, it is to be expected that a correlation of some sort will be found between the relative development of these structures and that of the œsophageal glands.

Accordingly, it seemed desirable to extend the investigation of the structure of the œsophagus to a much larger series of animals than has been considered hitherto by any single investigator, and to determine, as accurately as may be, the specializations which have arisen as a result of the response to the differences in the nature of the food on which these animals subsist. Among these, it might reasonably be expected that animals which live on coarse vegetable food would develop either a thickened epithelium, or a more completely cornified epithelium, or a layer of glands furnishing a lubricant secretion. It is, however, not by any means easy to estimate the degree of cornification of an epithelium except in those cases where a true stratum corneum composed of cells which have lost their nuclei is present. The thickness of the epithelium too is variable

from animal to animal of the same species, and in a single animal varies with the degree of extension of the membrane upon which it rests. Only the more pronounced differences in these respects may therefore be interpreted with caution from the standpoint of specialization.

It was apparent from the outset that very little help in interpreting the œsophageal glands of mammals could be obtained from the consideration of these structures in lower vertebrates, because glands occur in reptiles only in the form of imperfect crypts in certain turtles, and the so-called œsophageal glands of certain batrachia are, according to Bensley (00), in reality gastric glands.

Methods of Study.

One difficulty that at once presents itself in studies on the œsophagus is that of determining the point of transition of the pharynx into the œsophagus. In animals like the dog, where there is a transverse fold of the mucous membrane, corresponding in its position to the lower border of the cricoid cartilage, and to an actual change in structure of the mucous membrane, this is relatively easy, but in the majority of cases no such superficial line of demarcation exists, and the point of transition must be more or less arbitrarily established. In the descriptions which follow, the lower border of the cricoid cartilage has been taken as the point where the pharynx passes into the œsophagus. In his recent article on the œsophageal glands Haane (05) places the point of transition somewhat higher, at the level of the corniculate cartilage, but designates the portion of the tube included between this point and the lower level of the cricoid cartilage in the dog as "Œsophagus-vorraum." In order to include the doubtful region so designated by Haane, sections from this region have been studied in each mammal examined, but structures occurring above the distal margin of the cricoid cartilage have been referred to the pharynx, those below to the œsophagus.

In the case of the smaller mammals the entire œsophagus was fixed, in the larger mammals, where this was out of the question, a strip was taken including the whole length of the œsophagus.

For fixation, Zenker's fluid was employed, Bensley's alcohol-

bichromate-sublimate mixture being used where a more detailed study of the glandular epithelium was desired. The entire œsophagus or a strip, after fixation, was cut into lengths of 1 cm. to 2 cm., and imbedded in paraffin. From each of these segments, which were numbered consecutively from above downwards, sections were made at intervals of one millimeter, so that all portions of the œsophagus were examined. This method, however, did not exclude the possibility in the case of those animals where the results as regards the presence of glands were negative, that some glands were missed in the short unsectioned portions. Accordingly the following method devised by Bensley was employed, where the material was available, to make preparations in toto of the layer containing the glands, staining the latter selectively so that every gland lobule in the œsophagus was demonstrated clearly. The œsophagus was pinned out on cork and placed in 70 per cent. alcohol for 24 hours. Then, after a further stay of 24 hours in 95 per cent. alcohol, the mucous membrane was dissected off, by dividing the tela submucosa carefully with a scalpel close to the muscular tunic. In this way all the glands come off with the layer of submucosa which remains attached to the mucous membrane. The mucous membrane is placed in water for one hour, then transferred to a mixture of one part of strong muchæmatein (see Bensley, 03) and five parts of distilled water. In this staining solution the membrane remains for 48 hours, after which it is washed in distilled water and transferred to 95 per cent. alcohol containing two volumes per cent. of strong hydrochloric acid. In this solution the preparation remains until the glands stand out distinctly blue on a red background, when the preparation is washed in several changes of alcohol, dehydrated in absolute alcohol and cleared in benzole. Where the epithelium is thick, as in man, dog, etc., it stains so intensely that it interferes seriously with the transmission of light through the preparation. It is easy, however, to remove the epithelium by stripping off with forceps after clearing in benzole. By this means a preparation is obtained in which every gland of the œsophagus is clearly visible and their general relations to one another, the nature, course, and branching, of their ducts may be seen. Furthermore, in such prep-

arations the branching of the tubule may be studied with ease, thus avoiding the laborious method of reconstruction from sections. Because of the lack of sufficient material I was unable to apply the method in the case of the wild animals whose œsophagi were examined, but such preparations were made of all the domestic animals and of man.

For staining sections hæmatoxylin and eosin, iron hæmatoxylin, copper chrome hæmatoxylin, neutral gentian, muchæmatein, mucicarmine, Mallory's connective tissue stain and acid violet-saffranin were employed.

Opossum *(Didelphys virginiana)*.

The mucous membrane of the œsophagus of the opossum exhibits the usual transitory longitudinal folds observed in the empty œsophagus. About 1 cm. above the cardiac orifice of the stomach, however, these disappear, and their place is taken by permanent transverse folds of the mucous membrane approximately 0.5 mm. in width, and provided on their free surfaces with a network of secondary ridges. These folds are separated from one another by deep sulci and, as will appear later, owe their occurrence in part to the accumulation in the lamina propria mucosæ of masses of glands.

The epithelium of the œsophagus at its upper end is represented in Fig. 1. It consists of a layer of somewhat irregular thickness, owing to the projection into it, from below, of ridges longitudinal in direction, belonging to the lamina propria. In full grown animal weighing 3,000 grammes, the thickness of the epithelium at the level of the cricoid cartilage was, in the spaces between the connective-tissue ridges, 190-250 micra, on the summit of the ridges 72-110 micra. The irregularity in thickness presented by this epithelium in transverse sections is due to high ridges of the lamina propria, which are for the most part longitudinal in direction, but are connected with one another by lower transverse and oblique ridges, so that in sections parallel to the surface at the level of the ridges a connective tissue network is seen surrounding islets of epithelium, instead of the epithelial network seen at this level in sections of the epidermis. As described by Oppel (97) in Phalangista, Phascolarctus and Aepyprymnus, true papillæ are wanting in the opossum.

On the surface of the epithelium a well-defined stratum corneum is seen, of fairly uniform thickness, although it dips down somewhat in the intervals between the longitudinal ridges of the lamina propria. This corneous layer presents two distinct strata, which correspond in a general way in their appearance and staining reactions to the stratum lucidum and stratum corneum of the epidermis. The deeper layer, 35 micra in thickness, stains deeply in eosin, particularly at the deep and superficial margins, the intermediate por-

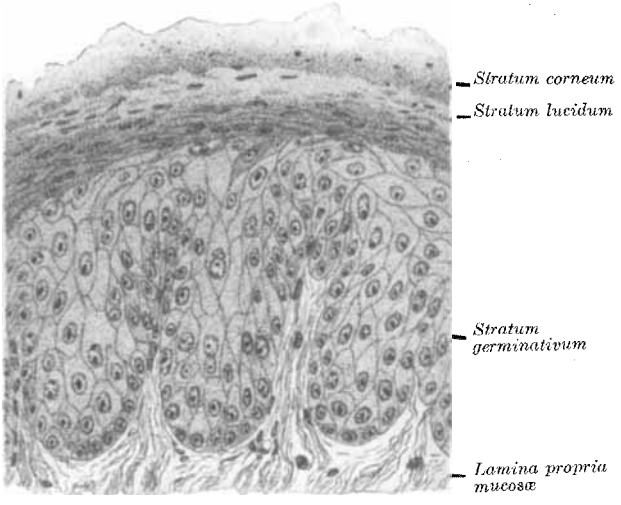

FIG. 1. Transverse section of epithelium of œsophagus of Didelphys at level of cricoid cartilage. × 120.

tion exhibiting, as is often the case with the stratum lucidum, patchy or irregular staining. This layer is composed of flattened cells, elongated, spindle-shaped in section, with a flattened nucleus rod-shaped in section. The superficial layer, 17 micra in thickness at its thickest portion, stains but faintly in eosin. It consists of cells of irregular polygonal shape similar to those of the stratum corneum of the epidermis with the exception that remains of the nucleus are to be found in them, in the form of shrunken remains of the nuclear membrane and one or two chromatic particles.

The stratum germinativum requires no special comment except that its superficial layers contain no granules of eleidin.

There is a gradual reduction in thickness of the epithelium going down the œsophagus. At the middle it is from 58-170 micra in thickness with a corneous layer 35 micra in thickness. The superficial layer of the corneous stratum here consists only of scattered cells of the sort described above.

At the point where the permanent transverse folds make their appearance about 1 cm. above the cardia there is a change in the character of the epithelium. On the surface and sides of these folds

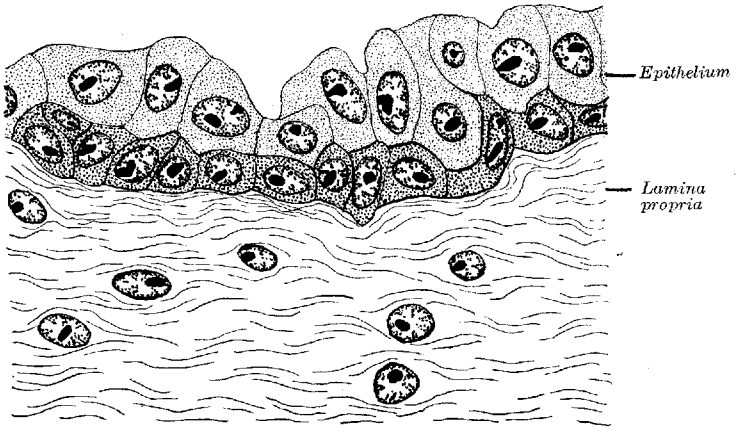

FIG. 2. Epithelium from side of transverse folds at lower end of œsophagus of Didelphys. × 750.

the epithelium varies from a double layer of cubical to polygonal cells, 10 micra in thickness (Fig. 2), to several layers of cells, the superficial layers flattened, 50 micra in thickness. The thin double layer of cells is found here and there on the sides of the transverse folds, the thicker epithelium on the summits. As shown in Fig. 2 there is frequently no sign at all of cornification of the superficial layer.

The lamina muscularis mucosæ is longitudinal in direction and is found throughout the whole œsophagus. At the lower level of the cricoid cartilage it makes its appearance as scattered bundles of

unstriated muscle. At the middle of the œsophagus it forms a continuous layer of considerable thickness (205 micra in an animal of 3 kg.) and increasing to 420 micra at the cardiac orifice of the stomach. In the lower portion, by reason of the fact that the glands are practically confined to the mucosa, the lamina muscularis mucosæ is separated by only a narrow band of collagenic connective tissue representing the tela submucosa, from the tunica muscularis.

Mucous glands are present throughout the whole length of the œsophagus and in the pharynx. In the upper part of the œsophagus

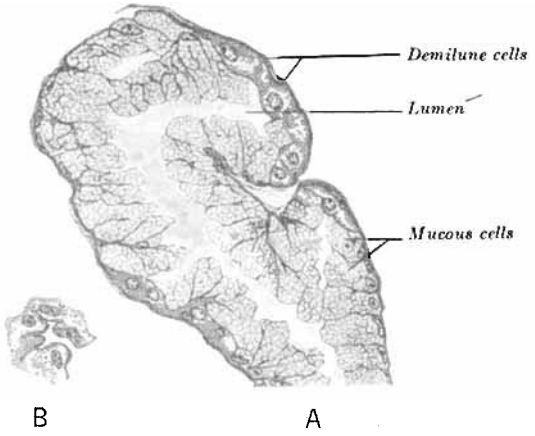

FIG. 3. A. Section of a tubule of an œsophageal gland of Didelphys showing mucous cells and demilunes. B. Group of demilune cells with central lumen and intercellular canaliculi. × 500.

they are located in the submucosa, but at the lower end where the transverse folds occur they are found in the lamina propria of these folds, superficial to the l. muscularis mucosæ, although here a few tubules may extend into the lamina muscularis mucosæ and even into the tunica muscularis.

The glands in all parts of the œsophagus of the opossum are mixed glands, that is to say they consist of mucous cells and demilunes or crescents. The latter are few in number at the upper end of the œsophagus, but at the lower end where the glands are located in the lamina propria mucosæ they are very abundant, as shown in Fig. 3.

The character of the mucous cells of these glands is well shown in Fig. 3 and requires no special description. Their secretory content stains selectively in muchæmatein.

The crescents (Figs. 3 and 4) are composed of cells which stain intensely in eosin. In the glands of the upper portion of the œsophagus they are to be found forming the characteristic crescent-shaped groups at the ends or along the sides of tubules. In the lower glands they form aggregates of considerable size, often surrounding a lateral diverticulum of the lumen of the gland so as to make a sort of sessile acinus on the side of a tubule. The character

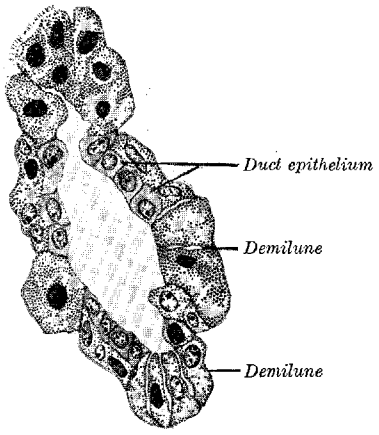

FIG. 4. Portion of duct of œsophageal gland from lower end of œsophagus of Didelphys showing demilune cells alternating with duct epithelium. × 500.

of the cells is the same at all points in the œsophagus. They are cuboidal in shape and the aggregate presents a rather remarkable resemblance to the parietal cells of the gastric glands. The cytoplasm is finely granular, but the granules are less crowded than in the parietal cells. Between the constituent cells of the complex, in iron hæmatoxylin preparations, may be seen fine intercellular secretion canaliculi, their outlines defined by fine cement lines. In Mallory preparations the granules along the canaliculi and on the lumen-border of the cell stain differently from the fine granules of the cytoplasm and probably represent the secretion antecedent of these

cells. There are no intracellular ductules. The crescents in the glands of the lower portion of the œsophagus are not confined to the mucous portion of the gland, but occur also in groups along the ducts, alternating with the non-secreting cubical epithelium of the ducts, as shown in Fig. 4.

The ducts of the glands are lined at their point of origin from the gland-tubule by a double layer of cuboidal cells. As they approach the surface the number of layers increases, there being a gradual transition to a stratified squamous epithelium. The majority of the ducts pass into the gland about the level of the deep border of the muscularis mucosæ. Frequently, however, they branch before penetrating the muscularis mucosæ, and occasionally they receive a small group of mucous tubules in the lamina propria or in the muscularis mucosæ. There are no aggregations of lymphoid tissue around the ducts nor are the latter enlarged to form ampullæ, as in the pig.

The ducts of the superficial glands at the lower end of the œsophagus are more numerous and the glandular masses are less complex. The ducts here open into the depressions formed by the secondary network of ridges on the surface of the folds and also at various points into the deep grooves between the principal folds.

The glandular tubules are supported by a thin basement membrane of reticulum, between which and the bases of the cell fine fibres resembling myofibrillæ may be seen. The latter stain red in Mallory's reticulum stain, and probably belong to stellate cells (Korbzellen), although this could not be demonstrated by the technique employed.

The tunica muscularis consists in the upper third of the œsophagus of striated muscle. At the middle of the œsophagus a few striated fibres are still to be found, but below this point it is all unstriated.

Rodentia.

The literature of this subject contains so many references to the structure of the œsophagus in Rodentia that it is unnecessary to describe in detail the conditions found in the different rodents examined. It will suffice to discuss those structures which may be con-

sidered to be specialized in some degree to meet the mechanical conditions imposed by the food.

The œsophagi of the following rodents were examined: Arctomys monax, Sciurus hudsonicus, Tamias striatus, Cavia, Erethizon dorsatus, Mus decumanus, Geomys bursarius, Lepus cuniculus, Lepus nuttalli mallurus. In the case of the porcupine (Erethizon) (Fig. 5 A) only the lower portion of the œsophagus about three centimeters

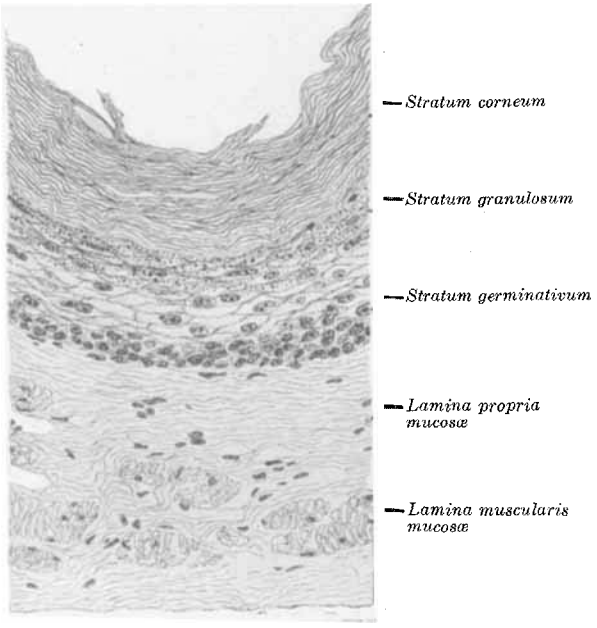

FIG. 5. A
Transverse section of tunica mucosa of œsophagus of Erethizon.

in length was available. In addition to the above genera the following rodents have been described by other authors: Mus musculus, Arvicola amphibius and Arvicola arvalis, Hypudæus arvalis, Spermophilus citillus.

With regard to the occurrence of glands, the results of all observations hitherto reported are negative except in the case of the rabbit, where glands are reported by Graff (80) and by Vogt and Yung (94), denied by Klein (71).

My observations are in accord with those of Ranvier (84), Brümmer (76) and others who deny the presence of œsophageal glands in rodents. In none of the species mentioned above are œsophageal glands to be found below the level of the cricoid cartilage. In the rabbit, pocket gopher (Geomys) and chipmunk (Tamias) groups of mucous glands were found above this layer in the submucosa of

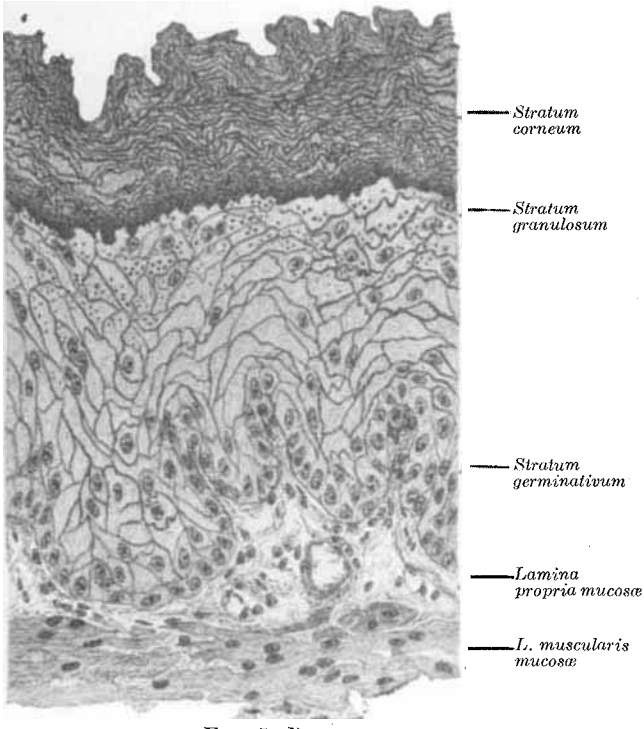

Fig. 5. B

Tunica mucosa of œsophagus of guinea pig. Showing true stratum corneum and stratum granulosum. × 120.

the pharynx, and it is probable that the occurrence of glands in this portion of the pharynx is responsible for the statements of Graff and of Vogt and of Yung that glands occur in the œsophagus of the rabbit.

The œsophageal epithelium in the rodents is a thick layer of stratified squamous cells presenting in the different members of the order two main types. One type (Fig. 5 A) is characterized by a very rapid

and complete cornification of the superficial layers of the epithelium to constitute a true stratum corneum composed of flattened cells wholly devoid of nuclei, and comprising over one-third of the total thickness of the epithelium. Below the stratum corneum in this type a true stratum granulosum is found consisting of two or more layers of cells, of elongated fusiform shape in section, containing numerous granules of eleidin staining blue in hæmalum. The stratum germinativum is relatively thin as compared with that of the second type. This type of epithelium is found in the guinea pig (Fig. 5 B), rat, pocket gopher and porcupine. The second type of epithelium (Fig. 6) also shows a considerable degree of cornification, but a true stratum corneum is not present, the superficial layers of flattened cells being nucleated and no stratum granulosum being found. In this epithelium the process of cornification appears to go on more gradually than in the first type and no sharp line can be drawn between the stratum corneum and the stratum germinativum. The superficial half of the epithelium nevertheless consists of flattened cells with elongated nuclei and stains more strongly in eosin than the deeper layer. Comparing this epithelium with that of the dog it is apparent that the degree of cornification is much greater in the rodent and that the thickness of the epithelium considering the relative sizes of the animals is much greater. True papillæ of the lamina propria mucosæ are not present in the rodents examined. In Cavia, Arctomys, Sciurus, Tamias and Lepus, however, as described by Strahl (89), the lamina propria mucosæ projects into the epithelium in the form of irregular ridges for the most part longitudinal in direction, and in Cavia and Tamias these have irregular summits which in places approximate the formation of papillæ. In Mus, Geomys, and Erethizon, there are neither ridges nor papillæ.

The l. muscularis mucosæ is present throughout the whole length of the œsophagus in all the rodents examined. It is particularly well developed in the squirrels, where it forms a continuous layer around the œsophagus.

The tunica muscularis in the rodents consists of striated fibres throughout the greater extent of the œsophagus. In Cavia, Geomys, Mus, Tamias, and Lepus the striated fibres are found to the cardiac

opening of the stomach. In Arctomys striated fibers are found right up to the cardia, but for a very short distance at the lower end of the œsophagus are mixed with smooth muscle. In Sciurus also there is a short distance at the lower end of the œsophagus in which smooth muscle is found. In Erethizon the outer layer of

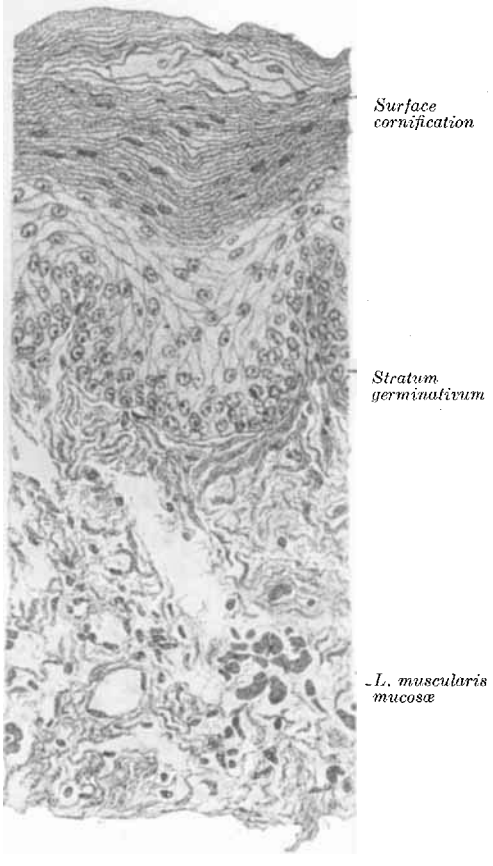

FIG. 6. Transverse section of tunica mucosa of Lepus nutalli mallurus. × 180.

muscle is striated to the cardia, but the inner layer has a thick lower sphincter composed of smooth fibres. In Muscardinus the striated fibres extend over onto the preventricular dilatation which, as is well known, contains fundus glands and is therefore to be regarded as a portion of the stomach.

Insectivora.

The only observations on the structure of the œsophagus in the Insectivora which I have been able to find are the descriptions of the œsophagus of Erinaceus given by Carlier (93) and Oppel (97). Carlier's description may be briefly summed up in the following statements: The epithelium is thick and of the ordinary type; the muscularis mucosæ is greatly developed consisting of large bundles of coarse non-striped fibers, longitudinally placed; the submucous coat is reduced to a minimum, due to the total absence of all glandular structures, mucous glands being entirely absent with the exception of a few scattered acini, situated near the cardiac end, internal to the muscularis mucosæ, and therefore in the mucous membrane. There are, however, according to Carlier, some serous glands in the submucosa of the organ, arranged in a ring round the cardiac orifice of the stomach, the long ducts of which pierce the muscle and epithelium to open just above the border of the œsophageal epithelium. The muscular coat consists throughout its whole extent of striped fibres. Oppel, on the other hand, found mucous glands in the upper portion of the œsophagus only. These glands showed cells of two types, as regards their affinity for hæmatoxylin and eosin respectively, although Oppel did not decide whether this difference was due to the physiological state of the cell or to a fundamental difference.

In Scalops aquaticus the conditions are very similar to those described by Oppel in Erinaceus. That is to say the glands are confined to the pharynx and to a very small portion of the upper extremity of the œsophagus.

The epithelium in Scalops is thick and fairly uniform in thickness throughout the length of the œsophagus, the increase in thickness towards the lower end of the œsophagus being but slight. At the upper end it measured 127 micra, at the lower end 139 micra. A true stratum corneum is not present, although a considerable degree of cornification of the superficial layers is apparent. The most superficial cells are nucleated and no stratum granulosum is to be seen. The superficial layers, about 24 micra in thickness, stain intensely in eosin. No true papillæ are present, although the deep

border of the epithelium presents a somewhat irregular outline in section.

The lamina muscularis mucosæ is well developed, except at the very beginning of the œsophagus. It forms a continuous layer composed of two or three layers of longitudinally disposed bundles of unstriated muscle.

The glands of the lower pharynx are mixed glands containing mucous portions with demilunes and serous alveoli.

The external muscular coat is composed of striated muscle throughout the whole length of the œsophagus.

Chiroptera.

This order is represented in my material by a single alcoholic specimen of Vespertilio fuscus, the brown bat.

The epithelium in the œsophagus of Vespertilio is thin (30-45 micra), and shows no stratum corneum, although the cells of the superficial two-thirds of the epithelium are much flattened. No papillæ are present.

The muscularis mucosæ is exceptionally well developed, reaching a thickness of 30 micra in the lower third of the œsophagus. It forms a continuous layer and consists of smooth muscle arranged longitudinally.

No glands are found at any level in the œsophagus.

The external muscular coat consists of striated muscle in the upper two-thirds and unstriated in the lower third.

Carnivora.

In the Carnivora the œsophagi of the following species, hitherto undescribed, have been examined: Procyon lotor, Lutreola vison, and Mephitis mephitica. One œsophagus of each species was available for this study including in the case of Procyon and Mephitis the whole of the œsophagus and the adjacent portions of the pharynx and stomach, in Lutreola the œsophagus and stomach only, so that in the latter animal the pharynx and transition region was not obtained. In addition the œsophagi of the cat and dog were examined to confirm the work of earlier observers. In these animals preparations

of the whole œsophagus were made according to the method outlined in the introduction in order to determine positively the distribution of glands in them. In the case of the cat three such preparations were made, all of which demonstrated the complete absence of glands below the level of the cricoid cartilage.

The œsophageal glands of the dog, like those of the opossum, are composed of two kinds of cells, mucous cells and serous demilunes. In this respect my observations confirm the statements of Klein (79), Renaut (97) and Helm (07) and are opposed to those of Rubeli (90).

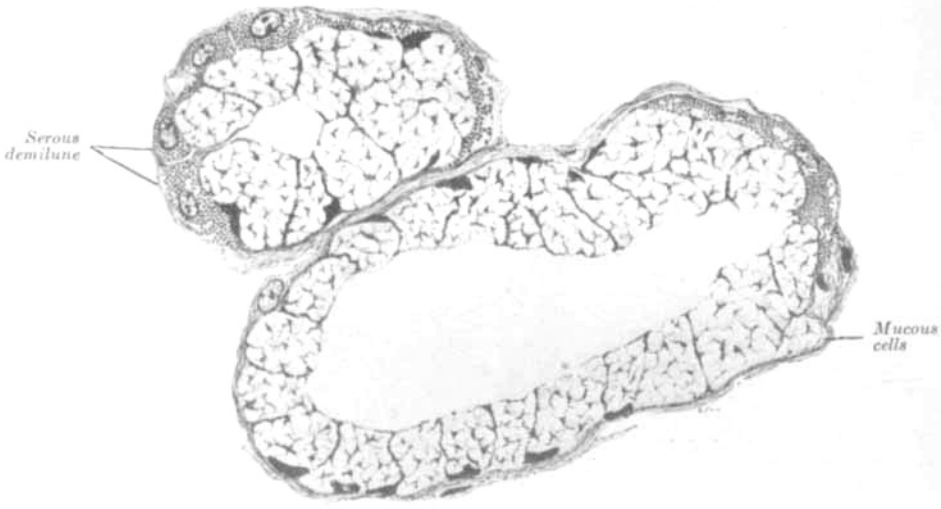

FIG. 7. Section of two tubules from œsophageal gland of the dog showing mucous cells and demilunes. × 750.

and Haane (05). The latter observer, it is true, does not specifically state that demilunes are absent, but implies it in the statement that he was unable to find intercellular secretion-capillaries. The demonstration of the demilunes in the œsophageal glands of the dog is no difficult matter if thin sections of well-fixed tissue are examined, and if an efficient differential staining method is employed, for they occur in relatively large numbers in all the œsophageal glands, although less numerous than in the glands of the opossum and raccoon (Procyon). For staining neutral saüreviolet-safranin is par-

ticularly valuable, the mucous cells staining red in this method, the demilunes violet. This method also shows well the intercellular secretion capillaries, although the iron hæmatoxylin method is preferable. The demilunes show the typical arangement as seen in the submaxillary gland and are provided, as indicated above, with

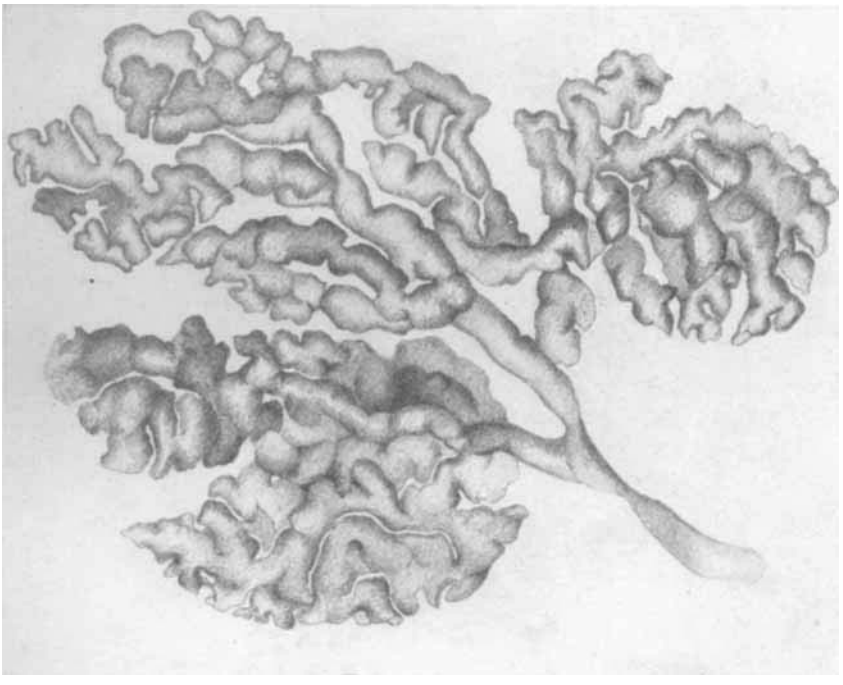

FIG. 8. Drawing of an entire gland from œsophagus of dog, showing tubulo-acinous character and mode of branching.

intercellular secretion capillaries resembling in every respect those found elsewhere (Fig. 7).

The shape and mode of branching of the gland is well shown in Fig. 8 drawn from a preparation stained in toto.

PROCYON LOTOR.

As in the dog, there is, in the raccoon, in the lower part of the pharynx, a circular fold of mucous membrane which projects into

the lumen and forms a superficial demarcation between the œsophagus and pharynx. This fold in the raccoon, however, is without glands.

The epithelium (Fig. 9) varies in thickness according to the degree of contraction of the surface upon which it rests from 158 micra to 220 micra. There is no marked thickening of the epithelium as the stomach is approached. The lower border of the epithelium is irregular in transverse sections owing to the projection into it of high ridges of the lamina propria mucosæ. These ridges are chiefly longitudinal in direction, but are connected with one another by numerous oblique ridges. On the summits of these ridges low conical papillæ are found.

The muscularis mucosæ is well developed throughout the whole œsophagus, consisting of two or more layers of longitudinal bundles of unstriated muscle.

Glands are present in the tela submucosa throughout the entire length of the œsophagus, and are fully as numerous as in the dog. The glandular lobules are ovoidal in shape, somewhat compressed from side to side and so placed that their long diameter coincides in direction with the long axis of the œsophagus. Many of the lobules have independent ducts, but in the majority of cases a duct divides below the lamina muscularis mucosæ into two ducts which enter adjacent lobules. The glands are of the tubulo-acinous type, the lobule being a system of highly branched tubules with small acini along their course and at their terminations. There is no difference between tubules and acini as to the character of the lining cells. The epithelium changes from duct epithelium to secreting epithelium at the point of entrance of the duct, so that all tubules within the lobule are lined exclusively by glandular epithelium.

The character of the glandular epithelium is well shown in Fig. 10. It consists of mucous cells and serous demilunes. The latter are very abundant and conspicuous. The mucous cells correspond in character with those of other mucous glands and require no special description. The demilunes in the glands of the upper part of the œsophagus have the characteristic crescentic shape in sections. In the glands of the lower portion of the œsophagus many demilunes

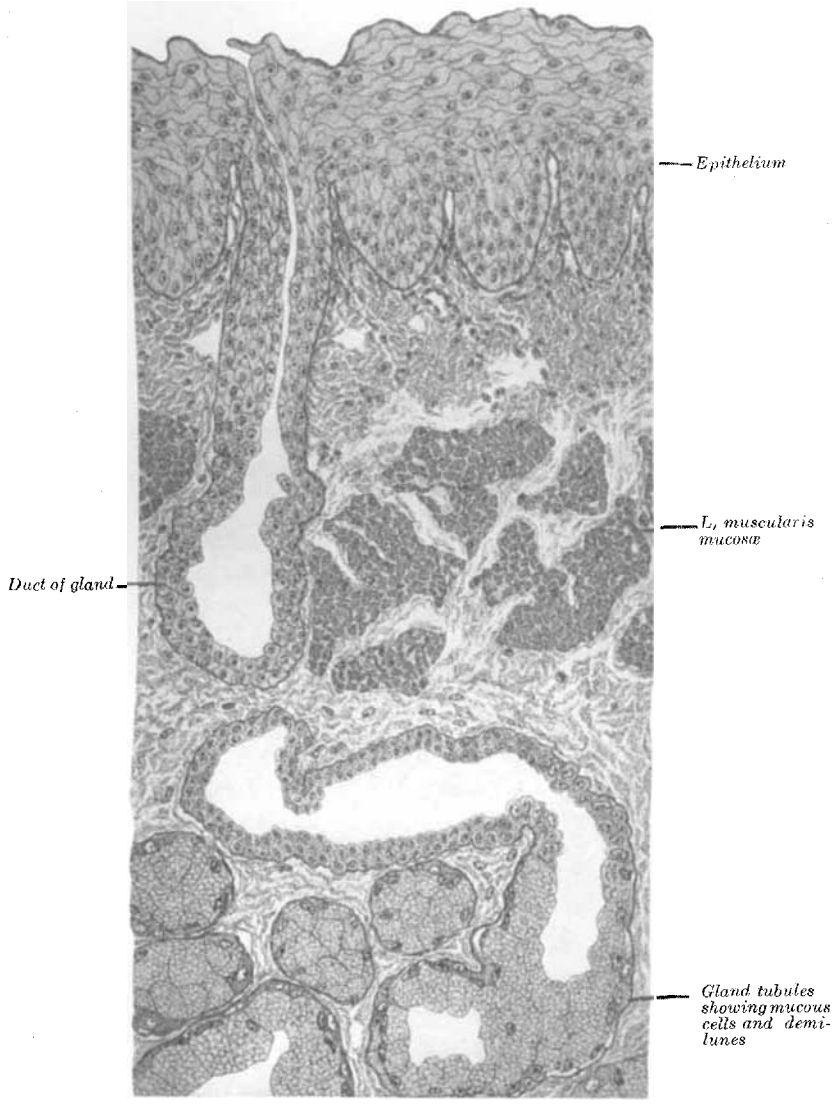

FIG. 9. Transverse section of tunica mucosa and part of tela submucosa of œsophagus of Procyon. × 120.

are so large that they form small sessile acini along the sides of the tubules. In both cases intercellular capillaries are seen in iron hæmatoxylin preparations, outlined by cement lines running between the adjacent surfaces of the cells. In the acinus-like demilunes of the glands at the lower end these intercellular ductules open into a central lumen which is directly continuous with the lumen of the main tubule. Although the material was not suitable for studying the secretory content of the cells, because of the fact that the œsophagus was fixed in Zenker's fluid fully an hour after the animal was

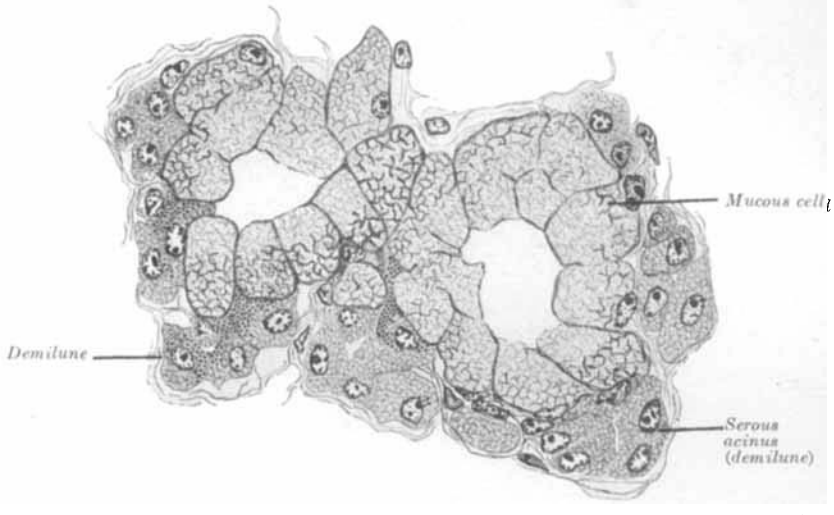

FIG. 10. Portion of tubule of œsophageal gland of Procyon showing mucous cells and large demilunes with secretion granules. × 500.

killed, yet in some of the more superficial glands the cells of the demilunes contained well-fixed secretion granules (Fig. 10), which stained strongly in eosin and in iron hæmatoxylin and which occupied the portion of the cells bordering on the lumen. No basal filaments, however, were demonstrated.

The ducts of the gland are lined for a very short distance at their origin from the lobule, by a low simple cubical epithelium. A short distance from its origin this changes to a two-layered epithelium, the cells of the surface layer having their long axes perpendicular to the basement membrane, those of the deep layer parallel to it.

In the upper part of the duct a third layer is added and the surface layer becomes flattened. The ducts enter the epithelium between the ridges of the lamina propria.

The ducts run perpendicular to the surface and have no ampulla-like enlargements. No lymphatic nodules nor accumulations of lymphocytes occur in relation to the ducts.

The tunica muscularis is composed of striated muscle throughout nearly its whole extent. In the stratum circulare smooth muscles make their appearance a short distance above the cardia and expand at the cardia into a lower sphincter.

Mephitis Mephitica.

In Mephitis the epithelium is extremely uneven in thickness owing to the fact that from the deep surface epithelial processes descend into the lamina propria mucosæ. The connective tissue separating these processes represents, somewhat more highly developed, the longitudinal and transverse ridges of the œsophagus of the raccoon. The thickness varies from 122 micra to 294 micra, the difference between these measurements indicating the height of the epithelial processes. The epithelium shows very little evidence of cornification, although the superficial layers of cells are much flattened and stain more readily in eosin than the deeper ones.

The lamina muscularis mucosæ begins at the upper end of the œsophagus as scattered bundles, but rapidly becomes a complete layer 47 to 118 micra in thickness, according to the degree of extension of the mucous membrane.

The only glands present in the œsophagus are found just at the cardiac orifice of the stomach. They are located in the submucosa and are similar in structure to the glands of the œsophagus of Procyon. The demilunes are particularly abundant and have the characteristic form and structure. The ducts begin in the lobules with a lining of cubical cells, beneath which is an imperfect second layer of cells. This second layer quickly becomes complete on going up the duct and additional layers are added as the surface is approached, as in œsophageal glands elsewhere. These glands are therefore in

every respect typical œsophageal glands and can not be confused with the neighboring cardiac glands of the stomach.

The tunica muscularis consists of striated muscle throughout its whole extent.

Lutreola Vison.

The epithelium in Lutreola is very similar to that in the cat. No true papillæ are present and there is a very slight indication of ridges of the lamina propria so that the deep border of the epithelium is fairly regular. The cornification is imperfect but is indicated by the different staining of the superficial layers of cells which are much flattened, but which retain their nuclei. The thickness is fairly uniform throughout except for such differences as are the result of tension.

The lamina muscularis mucosæ is well developed, forming a layer 50-80 micra in thickness at the upper end of the œsophagus and gradually increasing in thickness to 180 micra at the cardiac orifice.

A few glands only are present, and these are confined to the upper fourth of the œsophagus. They are similar in nature to the glands of the œsophagus of Procyon, that is they consist of mucous cells and demilunes.

Ungulata.

My observations on the structure of the œsophagus of the ungulates have been largely confirmatory of the work of Ellenberger (84), Rubeli (90), Haane (05), and Helm (07).

To ascertain beyond doubt the presence or absence of glands in the œsophagus of the sheep and ox, preparations were made of the whole œsophagus according to the method already outlined, but with negative results. These œsophagi contained no glands. In the case of the horse sections made at different levels were likewise devoid of glands.

In the œsophageal glands of the pig, I have found, in confirmation of Helm (07), demilunes of serous cells, but in smaller numbers than in any of the other animals whose glands were studied with the exception of man. They are, however, by no means infrequent,

although the complexes are smaller in size, more compressed, and more easily overlooked than in other animals. These demilunes are provided with intercellular secretion-canaliculi.

In all the ungulates examined, as might be expected, the epithelium shows a marked thickening, and an unusual degree of cornification. The condition in the sheep as shown in Fig. 14 is typical of that found in the sheep, ox and horse. The epithelium is thick and presents on its deep surface an irregular outline owing to the presence of longitudinal ridges of the lamina propria mucosæ. In addition, both on the summits of these ridges and between them there are extraordinarily long papillæ, for the most part simple, which penetrate the epithelium as far as the stratum corneum and even penetrate that layer for a short distance. A thick stratum corneum forms the outer portion of the epithelium, forming from one-third to one-fourth of the entire thickness of the epithelium, the thicker portions being found in the lower regions of the œsophagus. In this stratum corneum two secondary strata may be made out which may be compared in general with the strata lucidum and corneum of the plantar skin, although there are important differences in structure. Both layers are very homogeneous and transparent in the fresh condition, and in unstained alcohol-fixed sections. The deeper layer is composed of fusiform flattened cells, but with flattened nuclei. The superficial layer shows the wrinkled cell borders seen in section of the stratum corneum of the skin. No true stratum granulosum is present, but the superficial portion of the stratum germinatum shows indications of a change preparatory to cornification, in that the cell protoplasm of this layer stains more readily in fuchsin than the deeper layers. Nuclei are present in the cells of the most superficial layers of the stratum corneum, although they are much degenerated. Thus while a deep stratum corneum is present the changes do not involve the nuclei of the cells to the extent that they do in the guinea pig.

In the pig, also, the epithelium is thick, but the degree of cornification is much less than in the sheep, the contrast between the stratum germinativum and the stratum corneum less striking, and the transition less abrupt from the one layer to the other. We do not see

in the œsophagus of the pig the division of the stratum corneum into two layers as in the sheep, and in the pig nuclei are more numerous in the superficial layers and less degenerated. There is thus in these animals a very evident relation between the presence of glands and the degree of cornification of the epithelium.

An interesting fact in connection with the structure of the pig's œsophagus is the arrangement of the muscularis mucosæ. In the upper portion of the œsophagus where the glands are abundant there is no muscularis mucosæ. It makes its appearance a short distance above the point at which the glands begin to thin out and is well developed in the lower half of the œsophagus where there are few glands.

Man.

Much disagreement exists between observers as to the number and distribution of the œsophageal glands in man. According to Toldt (89) they are present in large numbers in the upper section of the œsophagus and are wholly wanting in the lower segment. According to Klein (71) they are of rare occurrence. Kossowski (80) on the other hand finds them most abundant at the lower end of the œsophagus near the cardia. Dobrowolski (94) found that there were considerable individual variations, but that the whole number did not exceed two hundred, of which two-thirds were in the upper half of the œsophagus. The latter observer's results were based on preparations of the entire œsophagus and his conclusions as to the individual variability are supported by the preparations which I have made by the method already outlined. The extent of the individual variations is well indicated by figures 15 and 16 which show the exact location of every glandular lobule in two human œsophagi. One of these contained 741 lobules pretty well distributed over the whole œsophagus with the exception of a short area at the beginning of the œsophagus and another near the cardiac end where the glands are relatively few in number. The other œsophagus had but 62 glandular lobules, 58 of which were found in a segment 4 cm. in length beginning 3 cm. below the cricoid cartilage. In a third œsophagus there were 140 lobules of which 43 were located in a

segment 3 cm. long at the lower end of the œsophagus. Above this a segment 3 cm. long was free from glands. Above this 37 glands were distributed over an area 10 cm. in length. At the upper end of the œsophagus 60 glands were distributed over a distance of 7 cm., this group being separated from the middle group by a segment 2 cm. in length devoid of glands. In addition to the glands there were 54 cysts of various sizes. As the figure (15) indicates, there

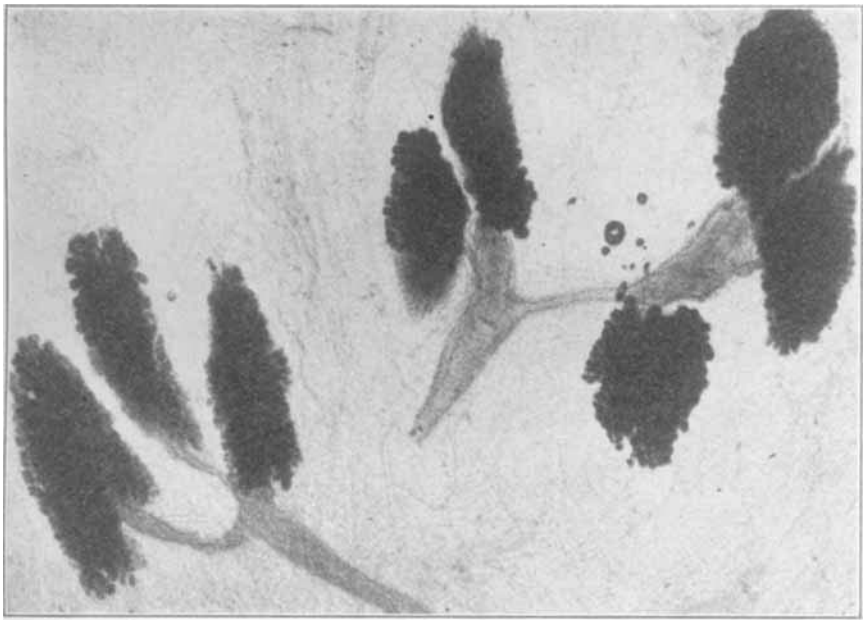

FIG. 11. Photomicrograph of two glands from human œsophagus stained in toto. The long axis of the œsophagus coincides with that of the glandular lobules and the ducts point obliquely toward the stomach.

is a marked tendency for the glands to be arranged in longitudinal rows parallel to the long axis of the œsophagus. These rows may be as many as eight in number at one transverse level and are not confined to the anterior surface and lateral surfaces as stated by Dobrowolski, but are distributed indifferently on all surfaces of the œsophagus.

The relation of the ducts to the lobules is well shown in Fig. 11.

Each duct is oblique in direction with reference to the axis of the œsophagus but has a general direction downward in the direction of the stomach. The descending portion of the duct lies in the tela submucosa close underneath the lamina muscularis mucosæ, and may reach a length of 4.6 mm., although the majority of them are much shorter. Each duct branches at its termination into from two to five rarely more secondary ducts, each of which enters a lobule. Ampullary dilatations of the ducts are of very common occurrence and affect most frequently the oblique portion of the main duct in the submucosa. Almost as frequent, however, are the dilatations into ampullæ of the secondary ducts at the point of emergence from the lobule or in the hilum of the lobule. The portion of the duct contained in the lamina propria mucosæ is frequently surrounded, as pointed out by Flesch (88) and Schaffer (97), by accumulations of leucocytes and often by true lymphatic nodules with a germinal center. At the point where the duct emerges from the lobule there is also, frequently, surrounding the duct, an accumulation of reticular tissue containing large numbers of leucocytes. The nature of the leucocytes found in these accumulations varies considerably, but in some cases the predominating cell is Unna's plasma cell. In other cases the lymphocytes predominate. In all cases, however, there are large numbers of plasma cells distributed along the duct and in the reticular tissue forming the framework of the gland, and in those cases where no nodule is present along the duct one finds occasionally the whole duct surrounded by a narrow layer of reticular tissue containing plasma cells and lymphocytes.

As regards the structure of the lobule and the character of the individual cells composing the gland, little can be added to the excellent description given of these structures by Schaffer (97) and the description which follows is largely confirmatory of his observations.

The lobular duct gives off within the hilus of the gland a series of intralobular ducts which are arranged radially around it and are of variable length, those which drain the portions of the lobule near the hilus being short, those which go to the terminal portions of the lobule longer. Each of these intralobular ducts drains a pyramidal

mass of tissue the apex of which is directed towards the duct, the base towards the periphery of the lobule. These pyramidal masses are the units of structure, being composed exclusively of tubules and acini lined by secreting cells. As indicated above, the gland is tubulo-acinous in type, the body of the unit composed of branching tubules which terminate in bulb-like acini, tubules and acini being occupied by the same type of epithelial cell. The acini show a slight expansion of the lumen and the cells are frequently longer in the acini than in the tubules, thus accounting for the difference in size.

To the question of the presence of demilunes in the œsophageal glands of man I have given much attention. In view of the fact that I have found these structures without difficulty in all œsophageal glands of other mammals it was my expectation that they would also be found in man. Accordingly I have studied carefully complete series of sections, 5 micra thick, of glands from three different œsophagi, using the methods of staining which I have found most efficient in demonstrating these structures in other mammals. The result of this study has, however, been wholly negative and I am forced to agree with Schaffer, who states that the human œsophageal glands are pure mucous glands without demilunes. Referring to the literature I find that neither Klein (79) nor Renaut (97), who are quoted in this connection by Schaffer and Oppel, specifically state that they found demilunes in the human œsophagus, although the former found them in the dog and Renaut's description applies in general to the dog and man. Böhm and v. Davidoff (95) state that there are but few mucous glands in the œsophagus but that when present they contain well marked demilunes, but it is difficult to determine whether these authors had before them the true œsophageal glands occurring in the submucosa, or the superficial glands of Rüdinger which have been shown by Schaffer (97) and Hewlett (00) to contain parietal cells and from which their illustration of the œsophageal glands of man is clearly taken.

The character of the mucous cells forming the secreting tubules is well shown in Fig. 12. Protoplasmic cells containing no mucin as described by Schaffer occur also in my preparations, whole groups

of tubules being of this character. These I interpret, as did Schaffer, as temporarily inactive mucous cells. These tubules are always surrounded by a tissue containing large numbers of plasma cells.

The ducts of the glands (Fig. 12) are lined by a stratified epithelium except in the very beginning in the gland where for a short distance, only 12 micra in some cases, a single layer of cylindrical cells is found. The intralobular ducts have a double layer of cells and the large ducts in the submucosa two to four layers of cells, the number of layers increasing as the surface of the mucosa is approached. The shape of the cells varies with the degree of tension of the surface, produced either by distension of the duct with secretion or by the

FIG. 12. Portion of a lobule of an œsophageal gland of man, showing entrance of duct and transition of duct epithelium to glandular epithelium. A. Lobular duct. B. Transitional duct lined by simple columnar epithelium. × 180.

formation of folds in the mucous membrane. In the relaxed duct the superficial layers of cells are cylindrical, the deeper layers polygonal except very near the epithelium, where the epithelium becomes stratified squamous. In the distended or stretched duct both superficial and deeper layers of cells become more or less fusiform in section. In all cases the superficial layers of cylindrical or flattened cells stain more strongly in eosin than the second layer, indicating a probable change in a slight degree of the protoplasm in the direction of cornification.

As regards the superior cardiac glands of Schaffer and Rüdinger I have been able to make no study of them owing to the absence of

suitably fixed material. In one out of four œsophagi of which total preparations were made to study the distribution of the glands, groups of these glands were found in the upper part of the œsophagus extending 4.5 cm. below the lower border of the cricoid cartilage. In this case twelve patches of these glands were found varying in size from 1 mm. to 15 mm. in length and from 1 mm. to 3 mm. in width.

The mucous tubules and acini are surrounded by a well marked basement membrane composed of reticulum, and the tubules are bound together by a reticular framework. No myoepithelial cells could be demonstrated between the basement membrane and the epithelium of the glandular tubules.

The epithelium in man is of considerable thickness, varying in this respect with age, and with the degree of tension of the mucous membrane. Another cause of variation in thickness in specimens of the human œsophagus is due to post-mortem loss of the superficial layers of cells owing to maceration. In the newborn child it has a thickness of 113 micra, in the adult from 260 to 440 micra.

The degree of cornification of the epithelium in man is about the same as in the pig and considerably less than in the sheep and ox, that is to to say that, although the superficial layers of cells show indications of chemical change in their greater transparency and in staining more readily in eosin, the degree of flattening of the cells is much less than in the animals mentioned, and oval nuclei, which stain well, are preserved even in the most superficial layers (Fig. 13).

The deep border of the epithelium is irregular owing to the presence of transitory folds of the lamina propria, described by Strahl (89) and more particularly owing to the presence of large numbers of high conical papillæ. The latter are arranged in linear rows running parallel to the axis of the œsophagus and resembling in their general arrangement those found in the skin of the palmar surfaces (Fig. 17). In some cases, as shown in the figure, the rows are composed of several ranks of papillæ, the individual papillæ being irregularly distributed.

The lamina muscularis mucosæ is well developed. It begins in the lower part of the pharynx as scattered bundles of longitudinally

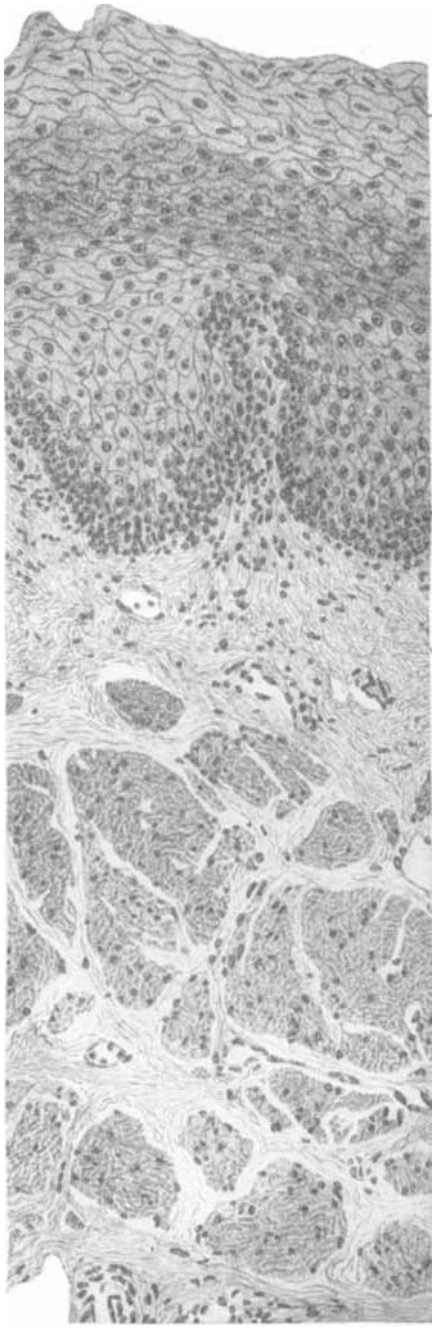

FIG. 13. Transverse section of tunica mucosa of human œsophagus. Ocular 3.

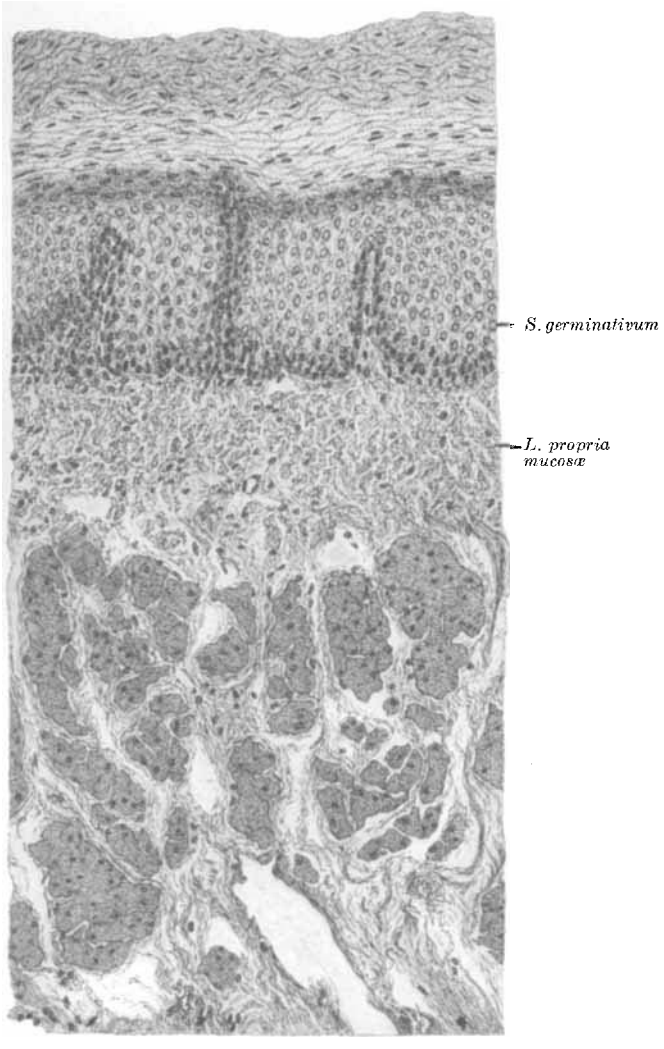

FIG. 14. Transverse section of tunica mucosa of œsophagus of sheep. × 120.

arranged unstriated muscle fibres, and rapidly becomes a complete layer at the upper end of the œsophagus, attaining in the adult a thickness of 0.4 mm.

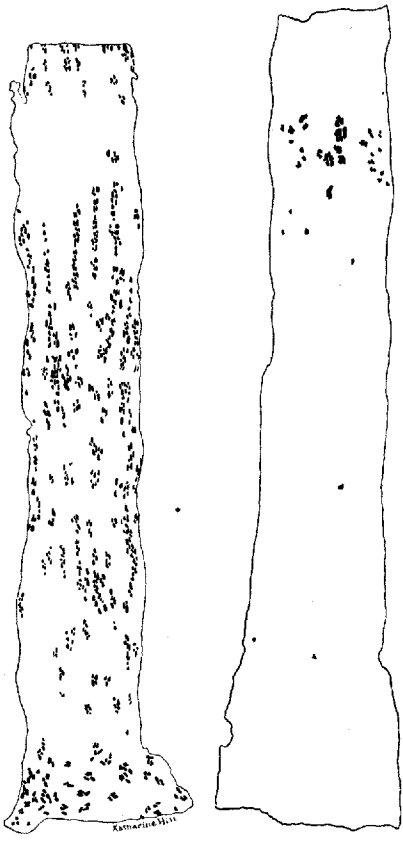

Fig. 15.

Fig. 16.

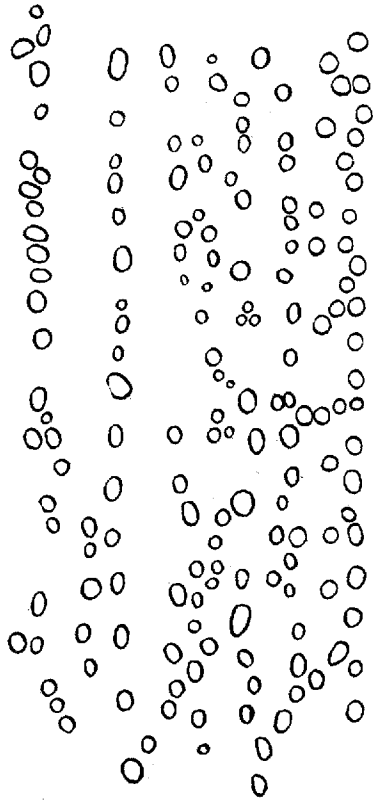

Fig. 17.

Figs 15 and 16. Diagrams showing exact location and relative sizes of every glandular lobule in two human œsophagi. Figures are reduced one-half. The figures represent the œsophagus as seen when cut open along the posterior border and spread out.

Fig. 17. Diagram showing exact distribution of papillæ on a small area of human œsophagus. The rows are parallel with the œsophageal axis.

As regards the character of the tunica muscularis my observations agree in the main with those of Welcker and Schweigger-Seidel

(61) except that I did not find the striated fibres extending so far down. The following table shows the condition found on the posterior wall of two human œsophagi.

No.	Length.	Striated.	Mixed.	Unstriated.
1.	Longit. 21 cm. Circ.	6.2 cm. 3.52 cm.	1.95 cm. 4.63 cm.	12.35cm. 12.35cm.
2.	Longit. 21.3 cm. Circ.	5.6 cm. 3.6 cm.	2.4 cm. 4.75 cm.	13.3 cm. 12.95 cm.

These measurements show that the unstriated fibers extend somewhat higher in the circular coat than in the longitudinal coat, but that scattered striated fibers extend to about the same level in both coats. Approximately the lower two-thirds of the œsophagus is provided with smooth fibres only. I did not find the striated fibres in the lower end of the œsophagus which have been described by Gillette (72) and Coakley (92). As Schaffer has shown, the unstriated fibres may occasionally extend in the circular coat as far as the lower border of the pharynx or even into the pharynx.

General Conclusions.

In addition to the specific data recorded in the preceding pages certain general conclusions may be drawn from the observations and from those of previous workers.

As regards the occurrence of œsophageal glands the species examined and those previously described may be divided into three groups:

A. Mammals in which the œsophageal glands are wholly lacking below the level of the cricoid cartilage. To this group belong all the rodents examined, including the following species:—Arctomys monax, Tamias striatus, Cavia, Erethizon dorsatus, Lepus cuniculus and Lepus nuttalli, Mus decumanus, Sciurus hudsonicus, and Geomys bursarius. In addition to these Sciurus vulgaris and Spermophilus citillus have been reported by Oppel as lacking œsophageal glands. Here also belong the ungulate species Bos taurus, Ovis aries and Equus caballus, the carnivor species Felis domestica, Vespertilio

fuscus belonging to the Chiroptera and according to Oppel the marsupial species, Trichosurus vulpecula, Aepyprymnus rufescens, and Phascolarctus cinereus.

B. Mammals in which the glands are few in number. To this group belong Erinaceus, Scalops and Lutreola in which a few mucous glands with demilunes occur in the upper end of the œsophagus, and Mephitis in which a few glands of similar nature are to be found at the lower end of the œsophagus.

C. To the third class belong a small group of mammals belonging to different orders in which the glands are present in considerable numbers. These are Didelphys, Procyon, Canis familiaris and C. vulpes. Meles taxus and Nasua rufa, in which glands occur in considerable numbers throughout the whole extent of the œsophagus, Sus scrofa domestica in which they are abundant in the upper half of the œsophagus and few in number in the lower half.

In structure the œsophageal glands are compound tubulo-alveolar glands, consisting, except in those of man, of two kinds of cells, mucous cells and serous cells. The latter elements, which have been overlooked by previous observers with the exception of Klein (79), Renaut (97) and Helm (07) are aggregated in the form of demilunes such as we find in the submaxillary gland of the dog, and like the demilunes of the salivary glands are provided with well defined intercellular secretion canaliculi. In the glands of the lower end of the œsophagi of Procyon and Didelphys these serous cells are so numerous that in many cases they form sessile alveoli on the sides of the mucous tubules with an independent lumen from which the secretion-canaliculi branch off. In man no demilunes could be found, thus confirming the observations of Schaffer.

A survey of the distribution of glands makes it apparent that the occurrence of œsophageal glands is the exception rather than the rule in mammals and that their presence bears no relation whatever to the mechanical qualities of the food nor to the completeness of mastication. Purely vegetable feeders are uniformly devoid of glands in the œsophagus and in many flesh feeders they are either few in number or wholly absent. Ranvier it is true explains the absence of glands in rodents on the basis of the thoroughness of mastication,

but if we examine the matter more closely we find that as a matter of fact the œsophagus of these animals has been specialized on account of the coarse character of the food but in other ways than by the production of mucous glands. On the other hand the theory that the glands are developed in proportion to the needs of the animal for lubrication of the food bolus does not adequately explain the fact that in many Carnivora glands are few in number or wholly wanting while in others they are very abundant. If we examine the cases of those animals which have a very large number of œsophageal glands we find that there is no common quality as regards efficiency of mastication relative to development of the salivary buccal and œsophageal glands, or consistence of the food which would serve to explain their presence. They are, however, without exception mixed feeders, and this suggests that it is the composition of the food rather than its consistence which has called forth the development of mucous glands in the œsophagus, or to express it differently, that the secretion of these glands has a chemical value rather than a mechanical one. This view is supported by the twofold cellular character of the glands, for it is difficult to understand why a serous gland should have been developed where the need was simply the mechanical need of lubrication.

In contrast to the glands the epithelium shows a very definite and constant relation to the character of the food, and it is in the epithelium that we find the œsophagus undergoing specialization in those animals which live on coarse vegetable food. The structure of the epithelium is thus an accurate index of the character of the food swallowed, inasmuch as we find a thickened and highly cornified epithelium in those animals which live on coarse food, particularly vegetable feeders, and a thin slightly cornified epithelium in animals living on soft food, for example, the carnivors.

Correlated with this thickening of the epithelium we find, as might be expected, an increase in the development of the muscularis mucosæ, the probable function of this layer being to retract the mucous membrane above the descending bolus of food. Conversely, the muscularis mucosæ and the epithelium exhibit these specializations in a less degree in those animals in which large numbers of

mucous glands are present, indicating that, although the glands have been developed primarily for another purpose, their secretion nevertheless serves the purpose of lubrication where it is present, and in so doing modifies the degree of specialization of the epithelium and muscularis mucosæ. For example in the pig, in the upper end of the œsophagus where glands are abundant, no muscularis mucosæ is to be found, while in the lower end where few glands are present, it is highly developed.

It will be noted that with regard to the processes of connective tissue which project into the epithelium and which are usually described as papillæ of the lamina propria mucosæ the observations here recorded confirm in general the conclusions of Strahl (89), who found that in many cases they were not true papillæ but elongated ridges of the lamina propria running in a direction parallel to the long axis of the œsophagus and connected with one another by oblique ridges. This is a matter in which it is very easy to be mistaken because ridges cut across are very similar in appearance to papillæ. It is only by examining carefully series of sections, or whole preparations of the epithelium, that this mistake can be avoided. Among the mammals examined true papillæ were found in the pig, ox, horse, sheep, and man and were associated in all these cases with longitudinal ridges of the lamina propria. In Didelphys, Arctomys, Sciurus, Tamias, Lepus, Canis, ridges only were present, although in Cavia and Tamias the irregular summits of the ridges afford suggestion of beginning papillæ. In Procyon there are longitudinal ridges also with suggestions of low papillæ on their summits, while in Mus, Geomys and Erethizon, there are neither ridges nor papillæ, but an epithelium of fairly uniform thickness. In Mephitis, finally, we have represented the exact opposite of connective tissue papillæ, inasmuch as the epithelium sends processes into the subjacent connective tissue. This is of course to be derived from a further development of the system of longitudinal and transverse ridges which have become so numerous and close that they surround papilla-like processes from the deep surface of the epithelium.

With regard to the phylogeny of the œsophageal glands, the fact that in whole orders no glands are to be found and that each of the

principal orders both of marsupials and placentals contain individuals wholly lacking in œsophageal glands indicates that these structures have been developed independently in the different orders in response to needs that have arisen as result of food specialization. The alternative hypothesis that they were originally present in all mammals and that they have disappeared from some is scarcely worth consideration in view of the general absence of similar glands in lower vertebrates.

In man alone is there any indication that the œsophageal glands are disappearing. Here the great variability in number of the glands and the constant presence of cyst formation and stasis of the secretion and atrophy of the glandular cells might be taken as an indication of a disappearing structure.

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BIBLIOGRAPHY.

BENSLEY, R. R., 00. The Œsophageal Glands of Urodela. Biological Bulletin, Lancaster. Vol. 2, pp.

———, 03. The Structure of the Glands of Brunner. The Decennial Publications, University of Chicago. Vol. 10, pp. 279-326.

BRÜMMER, J., 76. Anatomische und histologische Untersuchungen über den zusammengesetzten Magen verschiedener Säugetiere. Deutsche Ztschr. für Thiermed., Leipz., Bd. 2, pp. 158-186 and 299-319.

CARLIER, E. W. Contributions to the Histology of the Hedgehog (Erinaceus europaeus). Part I. The Alimentary Canal. J. Anat. and Physiol., London, Vol. 27, pp. 85-112.

COAKLEY, C. S., 92. The Arrangement of the Muscular Fibres of the Œsophagus. Researches of the Loomis Laboratory of the Univ. of the City of New York, Vol. 2, pp. 113-4.

DECKER, F., 92. Zur Physiologie des Fischdarmes, Festschr. Albert v. Kölliker, Leipzig, pp. 389-411.

DOBROWOLSKI, Z., 94. Lymphknötchen (folliculi lymphatici) in der Schleimhaut der Speiseröhre, des Magens, des Kehlkopfs, der Luftröhre und der Scheide. Beitr. z. path. Anat. u. z. allg. Path., Jena, Bd. 16, pp. 43-101.

ELLENBERGER, W., 94. Handbuch der vergleichenden Histologie und Physiologie der Haussäugetiere, bearbeitet von Bonnet, Csoker, Eichbaum, etc. Bd. I, Histologie, Berlin, Parey.

FLESH, M., '83. Ueber Beziehungen zwischen Lymphfollikeln und secretierenden Drüsen im Œsophagus. Anat. Anz., Jena, pp. 283-6.

GILLETTE, 72. Description et structure de la tunique musculaire de œsophage chez l'homme et chez les animaux. J. de l'anat. et physiol. (etc.), Paris, Vol. 8, pp. 617-44.

GRAFF, K., 80. Lehrbuch der Gewebe und Organe der Haussäugetiere. Jena.

HAANE, G., 05. Ueber die Drüsen des Œsophagus und des Uebergangsgebietes zwischen Pharynx und Œsophagus. Arch. f. wissensch. u. prakt. Thierh., Berlin, Vol. 31, pp. 466-83.

HELM, R., 07. Vergleichend anatomische und histologische Untersuchungen über den Œsophagus der Haussäugetiere. Inaug. Diss., Zürich.

HEWLETT, A. W., 01. The superficial glands of the Œsophagus. J. Exper. Med., New York, Vol. 5, pp. 319-32.

KLEIN, E., '71. Handbuch der Lehre von den Geweben, herausgegeben von S. Stricker. Leipzig, Bd. 1, pp. 378-88.

———, '79. Observations on the Structure of Cells and Nuclei. II. Epithelial and Gland-cells of Mammals. Quart. J. Micr. Sc., London, n. s., Vol. 19, pp. 125-75.

LANGLEY, J. N., 79. On the Changes in Pepsin-forming Glands during Secretion. Proc. Roy. Soc., London, Vol. 129, pp. 383-88.

OPPEL, A., 97. Lehrbuch der vergleichenden Mikroskopischen Anatomie der Wirbeltiere. Teil 2, Schlund und Darm. Jena, Fischer.

RANVIER, L., 84. Les membranes muqueuses et le système glandulaire. J. des microg., Paris, Vol. 7, pp. 77-86.

RENAUT, J., 97. Traité d'histologie pratique. Paris, Vol. 2, pp. 590-600.

RUBELL, C., 90. Ueber den Œsophagus des Menschen und der Hausthiere. Arch. f. wissensch. u. prakt. Thierh., Berlin, Vol. 16, pp. 1-28 and 161-98.

SCHAFFER, J., 97. Beiträge zur Histologie menschlicher Organe. IV. Zunge. V. Mundhöhle-Schlundkopf. VI. Œsophagus. VII. Cardia. Sitzungsb. d. k. Akad. d. Wissensch. Math.-Naturw. Cl., Wien, Vol. 106, Abth. 3, pp. 353-455.

STÖHR, P., 87. Ueber Schleimdrüsen. Festschr. Albert v. Kölliker, Leipzig, pp. 421-44.

STAHL, H., 89. Beiträge zur Kenntniss des Baues des Œsophagus und der Haut. Arch. f. Anat. u. Entwcklngsgsch., Leipzig, pp. 177-195.

SWIECICKI, H., v., 76. Untersuchungen über die Bildung und Ausscheidung des Pepsins bei Batrachiern. Arch. f. d. ges. Physiol., Bonn, Vol. 13, pp. 444-52.

TOLDT, C., '88. Lehrbuch der Gewebelehre mit vorzugsweiser Berücksichtigung des menschlichen Körpers. Stuttgart, Enke.

VOGT, C., and YUNG, E., 94. Lehrbuch der praktischen vergleichenden Anatomie. Braunschweig.