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Gross anatomical and micromorphological studies on the esophagus of the camel (Camelus dromedarius) during its ontogenetic development

Presented

by

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1. Introduction

The camel is considered as a very important animal, which has survived and served the human being for many centuries. It is a herbivore of the family camelidae and is characterized by a large body size and by the presence of one or two humps. From them the one-humped camel (Camelus dromedarius) is present in Egypt and the two-humped one (Camelus bactrianus) in Asia.

Indeed, the Egyptian farmer is greatly indebted to the camel for the transport of goods and providing him with meat, milk, wool and hides.

In spite of these facts, the camel has not received the adequate attention in anatomy and histology, when compared with the other farm animals. The amount of research, which can be traced in the available literature on the camel, is relatively few. We have selected the subject of the morphogenesis and histogenesis of the camel's esophagus in an attempt to give some information, peculiar for this animal, which is able to cross the desert for a long distance and for several weeks, without taking up water. This attracted our attention for the study of the structure

of the esophagus as a transport organ of the digestive system during the prenatal and postnatal phases. These studies include changes in the stratified squamous epithelium during the ontogeny, the appearance of the Lamina muscularis mucosae. The histogenesis and distribution of the esophageal glands and the Tunica muscularis.
These anatomical studies on the camel's esophagus shall be also an attempt to give us some information on the esophagus of a long-necked mammal. The length and diameter of the individual parts of the esophagus of the camel are important applied anatomical facts for the internal medicine and surgery, for example in introducing a stomach tube or probang. On the other hand, there are the relations between the deep cervical fascia (prevertebral and pretracheal laminae) and the esophagus, which are also of greater anatomical and surgical interest. We tried to clearify these in the different developmental stages of the camel. Special attention attracted the extension of the connective tissue in the retropharyngeal space from the pharyngo-esophageal junction to the dorsal mediastinum. Thus, we are able to judge the anatomical conditions for spreading of septic processes from an injured esophagus, a common carotid artery or a jugular vein. A further contribution will be rendered to the applied anatomy of

the carotid vagina (Vagina carotica) in the camel. This study may be of help in the comparative anatomy, surgery or medicine in the field of veterinary studies.

2. Review of literature

Reviewing the literature on the gross anatomy and histogenesis of the esophagus in camel, we found only few references. This was one of the reasons to conduct the present studies.

OMAR (1980) reported in his thesis on the topographic anatomy of the neck region of the one-humped camel (Camelus dromedarius). According to this author the Pars cervicalis of the esophagus begins from the caudal part of the pharynx and has an uniform diameter through its course in the neck, but narrows towards the thoracic inlet. The esophagus is fixed to the cricoid cartilage of the larynx by the M. cricooesophageus. The latter is a feeble muscle, triangular in outline. Its fibers start in the neighbourhood of the crico-arytenoid articulation and descends in a fan-shaped manner to be lost in the muscular tunic of the esophagus. In the cranial third of the neck region the esophagus lies caudal to the trachea. By the end of the third cervical vertebra it gradually shifts to the left of the trachea. At the cranial border of the fifth cervical vertebra, it is situated completely at the left side of the trachea.

It attains this position up to the thoracic inlet. Caudally and dorsally in the corresponding upper and lower halves of the neck, it is related to the M. longus colli. The esophagus contacts both lobes of the thyroid gland, which makes an impression on either side of it in the region of the axis. Beyond this, it is related to the Truncus vagosympathicus, A. carotis communis and N. laryngis recurrens. The latter nerve runs between the esophagus and the trachea, being deeply seated. Some small lymph nodules (about 6 - 12) are scattered along the space between the esophagus and the trachea on both sides. In addition to them, the superior deep cervical lymph nodes lie in contact at the beginning. The Pars cervicalis of the esophagus receives its blood supply from the A. carotis communis and V. jugularis externa. Numerous esophageal branches from the N. laryngis recurrens are also seen to supply the esophagus.

ENANY (1980) described in his thesis the gross anatomy and histology of the esophagus of the buffalo during its ontogenetic development. The position of the esophagus is unchanged during the whole developmental stages. At the pharyngo-esophageal junction, it lies dorsal to the larynx, at the cervical part, on the left of the trachea, at the thoracic part dorsal to the trachea. The length, the diameter

and the thickness of the esophageal wall increased with the age. The total length of the esophagus in the adult buffalo is about 96 cm, in the buffalo calf about 55 cm. The diameter is about 31 mm in the adult buffalo and about 12 mm in the buffalo-calf. This author has divided the esophagus of the buffalo into a pharyngo-esophageal junction, a cervical, thoracic and an abdominal portion. The latter one occurs only till the time of parturition, then it disappears successively due to the increasing size of the rumen of the calf.

The cervical part is the longest and narrowest part among all and the same time it has the thinnest wall. This ENANY (1980) related to the fact that the cervical part is surrounded by cervical muscles, which act on the esophageal wall. The thickest wall is found at the pharyngo-esophageal junction, due to the presence of the pharyngeal musculature here. The wide part has also the pharyngo-esophageal junction, followed by the thoracic part.

The Lamina epithelialis of the adult Egyptian water buffalo consists of a keratinized stratified squamous epithelium. In the buffalo fetus there is firstly only one epithelial layer. The number of the layers increases with age. Keratinization occurs about or immediately after parturition, also interpapillary peg-formation, anchoring the epithelium

to the Lamina propria.

The Lamina muscularis mucosae is absent at the pharyngo-esophageal junction, present in the cervical and thoracic parts. It occurs firstly at the buffalo-fetus of CRL 14 cm and increases steadily in thickness. The thickest Lamina muscularis mucosae is found in the thoracic part of the esophagus in the adult buffalo. Esophageal glands occur only in the ventral and lateral wall of the pharyngo-esophageal junction. Firstly they are epithelial sprouts, projecting from the Lamina epithelialis into the Lamina propria/submucosa (seen at CRL 9 cm stage). They increase in number with age. Later on, the excretory ducts became canalized (CRL 67 cm) first and after this the solid glandular epithelial sprouts (CRL 94 cm). The esophageal glands are of predominating mucous character.

The Tunica muscularis consists of a circularly and a longitudinally arranged layer of striated musculature, but in reality they are more spirally arranged. The circular layer increases in thickness towards the thoracic part.

The Tunica adventitia contains connective tissue of a loose texture at the pharyngo-esophageal junction and at the cervical part. At the thoracic portion it is surrounded by mediastinal pleura.

FUKAYA et al. (1979) reported on the course of the esophagus

in the thoracic cavity in bovine fetuses and neonates, based on the observation of resin casts of the thoracic hollow organs in both, fetuses and new born calves. Before the thoracic inlet, the esophagus was located on the left surface of the trachea, passing caudad on the ventral side of the left M. longus colli. Caudal the thoracic inlet the esophagus was slightly shifted to the left dorsal surface of the trachea, running caudad along the left M. longus colli. At the level of the 6th thoracic vertebra, where this muscle terminates, the esophagus was accompanied by the left comman carotid artery on its left side until the level of the 5th cervical vertebra, where the artery moved to the ventral side of the esophagus and left it soon. Near the thoracic inlet, at the level of the 7th cervical vertebra, the esophagus was in close contact to the left vertebral artery and vein, only for a short distance. Thus in the cervical part, below the level of the 3rd cervical vertebra, the esophagus has a constant caliber with neither a constriction nor an ampulla, being located on the left side of the body axis. Before and after the thoracic inlet, between 7th cervical vertebra and the 2nd thoracic vertebra, the esophagus curved downward and then upward. This concave curvature was also accompanied by a slight torsion in such a manner, that it passes just into the thoracic inlet.

The esophagus curved upward from the left side of the back surface of the trachea to be placed between the trachea and left longus colli muscle. At the level of the 4th thoracic vertebra, the esophagus had a constricted part, which was the first constrication, observed in fetuses and newborn calves in these studies. The thymus was well developed at the level of the 1st to the 4th thoracic vertebra. The constriction was observed between the dorso-caudal part of the developing thymus and the cranial border of the left cranial pulmonary lobe, seemingly caused by the pressure of these two organs. At the level of the 5th to the 6th thoracic vertebra the esophagus was shifted and completely placed on the back of the trachea, until the trachea bifurcated at the level of 6th thoracic vertebra, passing backward in the median plane of the body axis. At this site, the esophagus was in contact with the dorsally bending aortic arch on its left side, showing the second constriction, perhaps caused by the pressure of the aorta. At the same time, the esophagus gradually ran downward, detaching from the vertebral column to be placed in the center of the mediastinum. As a result, the esophagus showed a slight dorsally convex curvature and forwarded obliquely downward from this site. There after the esophagus passed backward in the mediastinum again, was based to the

left side of the body axis. Towards the Hiatus esophageus, which was located in the left part of the diaphragm, the esophagus showed as a result a slight horizontal curvature in the caudal mediastinum. At the level of the 10^{th} to the 11^{th} thoracic vertebrae, the esophagus was in contact with the Lnn. mediastinales caudales on its dorsal view, and at the level between the 9^{th} and 10^{th} ribs, from the lateral view. The esophagus was surrounded by both, the left and right lobes of the lung, and by the diaphragm, showing a third constriction. Between the second and third constriction the esophagus in many samples was relatively thick and swollen. In the investigated fetuses and new-born calves, since the diaphragm was completely attached to the cardia of the rumen, the abdominal part of the esophagus failed to be observed.

BERG et al. (1969) compared the relation between body weight and esophagus weight in buffalo fetuses and camel fetuses. They observed that the esophagus of buffalo developed more rapidly than that of the camel. Its average relative weight was higher in the camel (0.31%) than in the buffalo (0.19%). The authors assumed that this was fulfilled by the earlier starting point of the development of the esophagus in the camel. 1 gm of esphagus tissue was found at a body weight of 208.909 gm in the camel and 44.7 gm in the buffalo.

This was explained by the longer gestation period in the camel. In their studies on the prenatal growth of some organs in the Egyptian water buffalo TAHER et al. (1969) found the development of the buffalo following the formula: log y = 0.83 log x -2.1, where log y = expected esophagus weight, log x = body weight. Standard error of estimate syx = $\pm$ 0.3.

RAGHAVAN (1964) reported on the esophagus of the adult Indian water buffalo. According to this author, the esophagus was about 0.75 - 1m in length, which can be considered as in accordance with the data of SENGAR and SINGH (1970) (esophagus = 0.98 m). The diameter was found as to be 50 mm. No hints were given on the total esophageal length and that of the cervical, thoracic or abdominal part of the esophagus. RAGHAVAN (1964) indicated only, that the cervical part begins at the pharynx in the median line, behind the Aditus ad esophagem, above the rostral border of the cricoid cartilage, and passed backwards and downwards on the dorsal surface of the trachea till about the level of the third or fourth cervical vertebra. At this level, it crossed the trachea obliquely, placing itself along the left side to the thoracic inlet. The thoracic part began at the level of the 1st rib and continued its course till it reached the level of the 2nd or 3rd thoracic vertebra, where it

again crossed the left face of the trachea obliquely upwards to gain its dorsal surface. It continued this dorsal relation of the trachea to its bifurcation. As it passed through the mediastinum, it was pushed to the right of the aortic arch and lying to the right of the median line. It then passed upwards and backwards in the caudal mediastinum, inclined gradually once again to the left to enter the Hiatus esophagus of the diaphragm, passing through this opening. It gained the abdominal cavity and immediately terminated on the dome-like, rumino-reticular wall at the cardiac orifice. From this elucidates the practical absence of an abdominal part of the esophagus. This was also underlined by MULLER-BOTHA (1962) and HABEL (1975). They described the abdominal part of the bovine esophagus as absent, because of the close contact of the stomach with the diaphragm.

SENGAR and SINGH (1969) performed quantitative and qualitative studies on the esophagus of the prenatal and postnatal Indian buffalo. They observed that the esophagus remained an insignificant organ up to the second month of the intrauterine life. With straightening of the fetal posture at about the middle of the second month, it gained in length and assumed a well-defined shape with the elongation of the neck by about the end of the third month of

fetal life. It was further seen, that, while its absolute length increased in almost geometrical progression during the first half of the intrauterine life, its proportion to the total gut length showed a declining trend in the beginning, then it got almost constant to account for about 4% of the total gut length. After birth, it declined further to about 2.5%. As far as the tissue weight were concerned, it made about 3 - 3.5% of the total gut tissue or 0.27 - 0.12% (2^{nd} - 10^{th} month), which is in good accordance with the data given by BERG et al. (1969) (= 0.192).
Histologically the growing esophagus showed interesting changes, both in its musculature and mucosa. During the early fetal stages (50 days) the esophageal walls have had a well-defined muscularis and mucosa. The mucosa, which was almost smooth and without folds, had a well-defined epithelium, resting on a basement membrane and was covered with a single layer of squamous cells. There existed no distinction between the Lamina propria and the submucosa as the Lamina muscularis mucosae was not developed to this stage. Both, propria and submucosa, largely had a cellular nature with well-defined nuclei. The connective tissue fibers were not yet developed. With progress of time both, muscle and the mucosa, elaborated. More squamous cell layers also grow in thickness so much, so that by about the middle

of gestation, the fetal esophagus developed almost all these features, true of an adult, except that the squamous cells did not get keratinized. The blending propria and submucosa got differentiated with the well development of the Lamina muscularis mucosae. The two started changing their cellular nature to that of the fibrous type. By about the full-term fetus the keratinization began in the top squamous cells of the epithelium. At birth it got fully cornified to resemble that of adult in almost all respect. SENGAR and SINGH (1970) investigated the esophagus of adult female Indian buffaloes and described its position as running dorsally to the trachea in the neck and between trachea and aorta in the thorax to the diaphragm.

Its length was found to be variable in different animal depending on their body length in general and that of the neck in particular. The absolute length of the esophagus was found as 98.21 $\pm$ 0.92 cm. Histologically the esophageal walls of the Indian water buffalo had the usual four layers: outermost the adventitia, next to it the muscularis in the middle the submucosa and as the inner most layer the mucosa. The adventitia consisted of a thin layer of fibrous connective tissue. It got changed to serosa with the incorporation of the visceral peritoneum on its abdominal part at its passage through the Hiatus esophageus. The muscularis,

which contributed maximal to the esophageal wall, consisted of two layers, the inner circular and outer longitudinal one. The disposition pattern of the two muscle layers in relation to each other was subjected to great variation. The muscle fibers of both were striated throughout its length and did not change to smooth. A well developed intermuscular nerve plexus reported to lie in between these layers in some sections. The submucosa consisted of loose connective tissue, which had a considerable amount of elasticity, permitting the organ to stretch out at the time of swallowing and regurgitation of the bolus. It contained a large number of lymphatics, blood vessels and nerves. Deep esophageal glands could not be identified. The epithelium of the mucous membrane was thick and of stratified squamous type with a cornified border. It was deeply indented by the papilla of the Lamina propria mucosae, which consisted of a narrow band of loose connective tissue and did not contain either the esophageal cardiac glands or superficial esophageal glands. The Lamina muscularis mucosae consisted of one or two layers of smooth muscle bundles, disposed longitudinally. It was almost insignificant in the cranial region and got quite prominent in the caudal portion of the esophagus.

In a later publication SENGAR and SINGH (1971) reiterated

partially the description of the above-mentioned quantitative data. They observed that the esophagus made up 18.4% of the total gut length during the second month of the intrauterine life. It had a retarded growth (as percentage of the total gut length) although it was about 4% at birth and went further down to only 2.45% of the adult age. The esophageal tissue weight was 3.55% during the third month of gestation and showed an increased growth during the middle of gestation. It returned back to 3.66% at the birth and then maintained almost on this level. The relations of the esophagus in bovine were described by WILKENS and ROSENBERGER (1957), RAGHAVAN (1964), KOCH (1970), DYCE and WENSING (1971), BERG (1973, 1974), HABEL (1975), KRAHMER et al. (1976) and NANY (1980). According to these authors, the bovine esophagus was related: at its origin, to the M. rectus capitis ventralis major dorsally and cricoid cartilage ventrally, at the level of its crossing over to the left face of the trachea to the M. longus colli dorsally and the trachea ventrally; at the level of the third cervical vertebra it was related to the left M. longus colli dorsally, the vagosympathetic trunk, common carotid artery and internal jugular vein laterally and the trachea medially; at the level of the thoracic inlet to the left external jugular vein laterally and to the trachea medially;

at the level of cranial and middle mediastinum to the thoracic duct and aortic arch on the left, to the M. longus colli, the right large trunk of the right costo-cervical vein and the right; at the level of its course through the caudal mediastinum to the dorsal and ventral esophageal continuation of the N. vagi on the respective parts to the right and left lung on the corresponding sides and the bronchial and esophageal arteries on its left.

BERG (1973, 1974) discussed the applied topographical anatomy of the dorsally convex cephalo-cervical curvature and of the ventrally convex cervico-thoracic curvature of the bovine esophagus.

LEESE (1927) described the pharynx and esophagus of the camel. The pharynx is remarkable for its length and narrowness and its partly divided into an anterior and posterior chamber by a thick transverse fold of mucous membrane, depending on its roof. The anterior chamber forms a pouch above this fold, the favourite resting place of the "camel bot". There are no guttural pouches. The gullet or esophagus has no special features, except its length.

According to NICKEL et al. (1973), the esophagus of the cattle has three curvatures. One is convex dorsally, located between the pharynx and the proximal part of the esophagus. The next is concave ventrally and is situated cranially

to the thoracic inlet, extending to the level of the first 2 or 3 thoracic vertebrae. The two curvatures are flexible and easily vary in location, according to the up and down movement of the head. The remaining one is convex dorsally and is located approximately in the center of thorax, passing above the base of the heart and on the bifurcation of the trachea.

TIWARI (1977) investigated microscopically the esophagus of 5 buffalo calves, 2 to 5 years of age. The mucosa was longitudinally folded and lined by stratified squamous, parakeratotic epithelium, since even the most superficial layers of the epithelium contained conspicuous prominent nuclei. The basal layer of the epithelium consisted of cuboidal to columnar cells with darkly stained nuclei. The Lamina propria and submucosa consisted of coarse areolar connective tissue. They contained arterioles and a zone of a large number of capillaries, just below the basal layer of the epithelium. The papillary bodies originated from the Lamina propria, extended deep (even up to the middle of the thickness of the epithelium) in vertical or oblique direction and their cores contained blood capillaries. The Lamina propria was separated from the underlying submucosa by a Lamina muscularis mucosae. This longitudinally oriented muscular tunic consists of isolated

thin bundles of smooth muscle cells, which did not form a continuous sheet at the cranial ends, but formed a complete thick sheet of muscle fibers caudally. The texture of the submucosa was more loose towards the Lamina propria than towards the Tunica muscularis. Though much less in amount the content of elastic fibres was comparatively more towards the caudal than the cranial end of the esophagus. The submucosa at the pharyngo-esophageal junction has a mucous type of glands. Elsewhere the glands were absent. The acini of the submucosal glands were lined by cuboidal to columnar cells with distinct cell boundaries. Flattened nuclei were placed at the bases of the cells. The cytoplasm of the lining cells showed a reticulated appearance and stained PAS-positive, indicating the presence of a mucous substance in it. The ducts of the acini were lined by flattened to cuboidal cell types. Subsequently, the thickness increased to 2 - 3 cell layers and the terminal part of the duct was lined by stratified squamous epithelium. The reticular fibers formed a thick network around the acini and their ducts. The Tunica muscularis consisted of spirally or obliquely arranged striated muscle fibers. In the inner layer, the fibers of the two sides crossed each other dorsally and ventrally. The fibers of the outer layer of the tunic were spirally arranged, but did not

appear to intercross the fibers of the other side. Because of the spiral arrangement, the histological sections showed the fibers of the two layers, arranged longitudinally obliquely or circularly with a changing direction in the same section.

BUSCH (1980) investigated 22 dogs, using the light scanning electron microscopical technique. The esophageal Tunica muscularis did not consist of an outer longitudinal and inner circular layer, but of two layers of skeletal muscle, forming screw-like fascicles that run in the opposite directions. Sphincter-like muscle fiber bundles in the upper cervical and abdominal part were closely connected with the tubular part of the esophagus. His morphological findings indicate that the esophagus of dog should not be considered to be an useful model for the elucidation of human esophageal malfunctions and their therapy.

RAMKRISHNA and TIWARI (1978) studied the esophagus of the goat during prenatal life. According to these authors the mucosa of the esophagus was folded, except at the caudal end. A non-keratinized stratified epithelium, rested on a distinct basement membrane and lined the mucosa. The superficial layer of the stratified epithelium consisted of flat and vesicular, non-keratinized cells with centrally placed flattened or oval nuclei. The middle layer presented

large polyhedral cells with distinct cell boundaries. The open-faced, eccentrically placed nuclei of these cells were irregular in shape and placed towards the free surface of the epithelium or towards the center of the cells. The cytoplasm was homogeneous and hyaline. The basal layer of the epithelium consisted of low columnar cells with oval or rounded, open-faced nuclei. The Lamina propria and submucosa consisted of undifferentiated mesenchymal cells. These subsequently got differentiated into reticular and collagenic fibers. Elastic fibers were not demonstrable. The Lamina muscularis mucosae, separating the Lamina propria from the submucosa, for the first time appeared at the caudal end. Then, at the cranial end of the esophagus. The superficial glands, were not developed in the esophagus of caprine fetuses. The submucosa presented a dense layer of fibroblasts, close to the Lamina muscularis mucosae and Tunica muscularis with a loose character in the mid-portion of the tunic. The Tunica muscularis consisted

cells into the striated variety at the cranial and, where the caudal ones end, did not show this change.

STINSON and CALHOUN (1976) mentioned the glands in the submucosa of the different domestic animals as mixed ones, containing mucous acini with serous dimilunes, characteristic in this layer in pig and dog. In the pig, the glands are abundant in the cranial half, but do not extend into the caudal half, where as in the dog they are present, throughout extending into the cardiac region of the stomach. The density of the glands may be as much as four times near the stomach. The glands are present only at the pharyngo-esophageal junction in the horse, cat and ruminants. Mixed acini and demilunes occur in cattle. They added that the lamina muscularis mucosae as longitudinally oriented smooth muscle bundles. It was absent in the crainal end of the esophagus of the pig and dog, but the cat, horse and ruminant have and isolated smooth muscle bundles near the pharynx, which increased in number and became confluent towards the caudal region.

COPENHAVER et al. (1971) mentioned the glands of the esophagus in human being as typical mucous alveoli.

WAKURI and MUTO (1972) studied the terminal glandular portions of the esophageal glands of cattle electronmicroscopically. Mucous and serous cells could be recognized

with the mucous cells being the more numerous myoepithelial cells, situated between the basal surface of the secretory cells and the basement membrane. The cytoplasm of the myoepithelial cells was packed with filamentous structures and it was concluded that these cells were contractile.

LESBRE (1903) reported about the morphology and structure of the esophagus in the two-humped camel (Camelus bactrianus) and found the esophagus extremely dilated and dilatable. Its cranial opening was wide. Externally it continued the pharynx in a nearly imperceptible manner and it could be seen that it was widened at its both extremities. In the condition of moderate dilatation, it decreased much in caliber over the trachea. Its length was closely related to that of the neck. It reached about 2 m. The mucous membrane of the esophagus adhered very strongly to the Tunica muscularis. This adherence especially bordered on a great number of small glandular end-pieces, which were easily to palpate or to touch and which were spread between the two tunicae. (Microscopically it was found, that these are cluster-like glands with a clear mucous epithelium, each of which has had a length of ¼ - ½ mm and a thickness of 1 - 2/10 mm. There was no one of the examined slides, which contained not at least one of them. These glands rested on the Tunica muscularis, underneath a layer of relatively

large veins. The outer membrane of the mucosa was bristly by small conical or nipple-like papillae, dipping into the mucous body of the epithelium. The total thickness of them was about 1/5 mm.

This extreme development of the glands, which the author has observed also in the pharynx and mouth cavity, explains the gushes of saliva, which the camel voluntary as also frequently throw out through the mouth cavity, in keeping the first passages of the digestive system in a constant humid condition. It facilitates probably the resistance against thirst, which this animal presents to a high degree.

The Tunica muscularis of the esophagus of the camel is relatively thin, of red colour and the whole extention formed by circularly running fibers at its surface, by longitudinally or more or less spirally running ones in the depth.

HEGAZI (1945) reported, that the esophagus of the camel leaves the pharynx at the cricoid cartilage of the larynx, followed the dorsal surface of the trachea with a slight inclination to the left side to enter the thorax. He added, that the esophagus was constricted at two points along its course, at the entrance of the thorax and the esophageal hiatus of the diaphragm. He explained that the cervical portion was relatively long, due to the great length of

neck. It was related at its beginning to the thyroid gland on both sides, then to the inferior laryngeal nerve. After a short course it deviated to the left side and became completely on the left side of the trachea at the junction between the upper third with the lower two thirds of the neck. Then it was compressed from side to side.

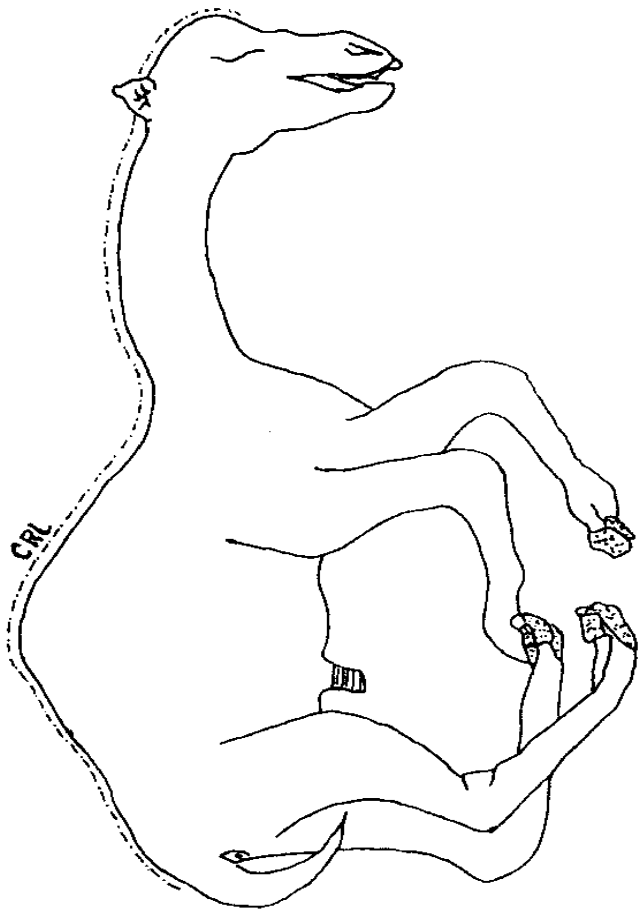
3. Material and methods

This thesis comprises anatomical and histological studies, for which different materials were collected and treated with different methods.

Anatomical studies:

Nineteen with a CVRL of 20-100 cm, a young camel, of 1.5 years of age, and two adult camels, 5 and 6 years of age, were used for the anatomical studies. The material was collected from the Cairo abattoir, after measuring the crown vertebral rump length (CVRL) by a flexible cloth tape. The fetuses were immediately injected with 10% formaline intrathoracically and put, together with the esophagi of the young and adult camels, into 10% formaline. Here they were kept till the time of dissection . The description of the position, relations and the course of the esphagus, lateral and ventral dissections and cross sections were performed.

All the measurements of the esophagus were taken from fixed specimens by a flexible cloth tape. These measurements



include the total length of the esophagus as also the length of its individual parts (cervical and thoracic parts). Furthermore the diameter was taken at the level of the larynx, of the 4th cervical vertebra, of the thoracic inlet, of the base of the heart and at the level cranial to the Hiatus esophageus.

To obtain the diameter of the esophagus, the exophagus was opened and the total circumference considered as 2 π r. We calculated the radius (r) and from this the diameter (2 r = d).

For the lateral dissection the following fetuses were used:

Two camel fetus of CVRL 22 cm.
" " " " 30 cm.
" " " " 43 cm.
" " " " 70 cm.
" " " " 79 cm.
" " " " 100 cm.

For the ventral dissection the following fetuses were used:

Two camel fetus of CVRL 20. cm.
" " " " 30 cm.
" " " " 40 cm.

Fig. 2 Diagrammatic representation showing the different levels of the cross-sections through the neck and thorax

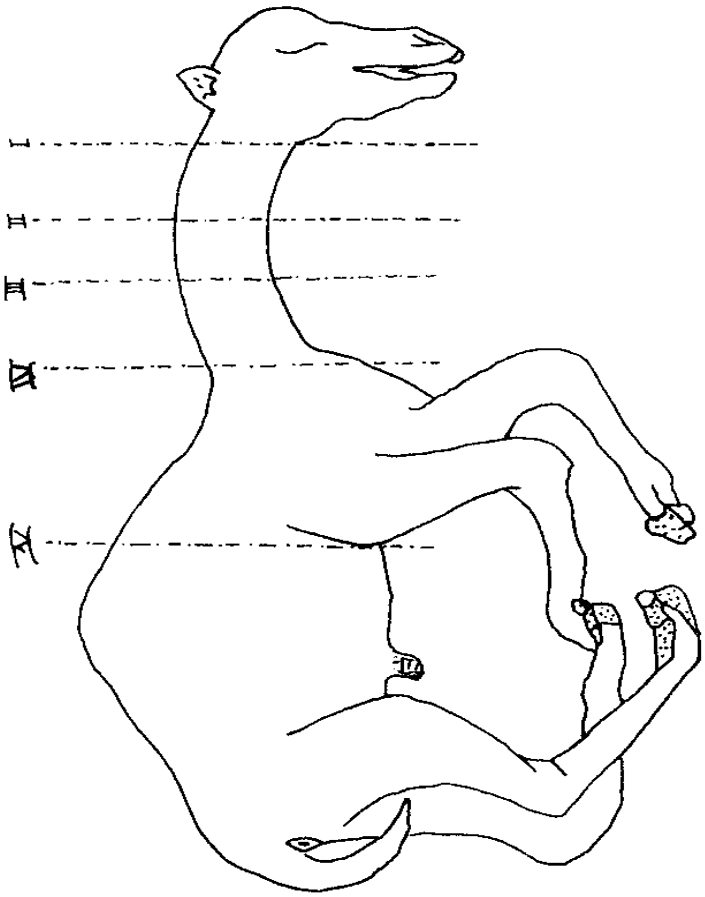
I Cross-section through the neck at the level of the larynx

II Cross-section through the neck at the level of the third cervical vertebra

III Cross-section through the neck at the level of the fifth cervical vertebra

IV Cross-section at the level of the thoracic inlet

V Cross-section through the thorax at the level of the fifth rib.



camel fetus of CRL 55 cm
" " " " 62 cm.

For the cross-sections the following fetuses were used:
camel fetus of CRL 25 cm
" " " " 36 cm
" " " " 40 cm
" " " " 70 cm
" " " " 80 cm.

Histological studies:

The samples for the histological studies were taken from 10 fetuses, the young camel (1½ years) and the adult camel (6 years).

The camel fetuses were of the following developmental stages:
camel fetuses of CRL 2 cm
" " " " 13 cm
" " " " 25 cm
" " " " 30 cm
" " " " 41 cm
" " " " 52 cm
" " " " 64 cm
" " " " 75 cm
" " " " 82 cm
" " " " 95 cm.

The samples were taken from all portions of the esophagus (pharyngo-esophageal junction, the middle cervical part, at the level of thoracic inlet, at the level of the base of the heart, cranial from the esophageal hiatus).
They were treated according to the classical paraffin technique (fixation in 10% formaline for 48 hours, dehydration in graded series of ethyl alcohol, clearing by xylene, embedded in paraffin, cut into section of 5 um in thickness).
The following three stains were used:

1) Hematoxylin (after HARRIS, 1900) and eosin for general studies.
2) VAN GIESON (1889) stain for the differentiation of collagenous fibers, smooth musculature and glands.
3) Elastic stain after WEIGERT (1898) for the detection of elastic fibers.

4. Anatomical results

4.1. Cross-sections:

The esophagus is redbrown in colour and the mucosa is firmaly attached to the underlying tissue. Under the mucosa small nodules are palpable. The esophagus increases in length during the ontogenetic development. Thus the total length measures about 12 cm in the camel fetuses of 22 cm CVRL and will reach about 175 cm in the adult camel (table 1). Also the esophageal diameter increases several times from the camel fetus CVRL 22 cm - 1.2 mm) till to the adult camel (22.60 mm) (table 2).

For description, we have divided the esophagus into three parts: pharngo-esophageal junction, cervical part, and thoracis part.

The pharyngo-esophageal junction is studied by a cross - section at the level of the larynx (fig. 3).

The cervical part we have studied at two cross-sections:

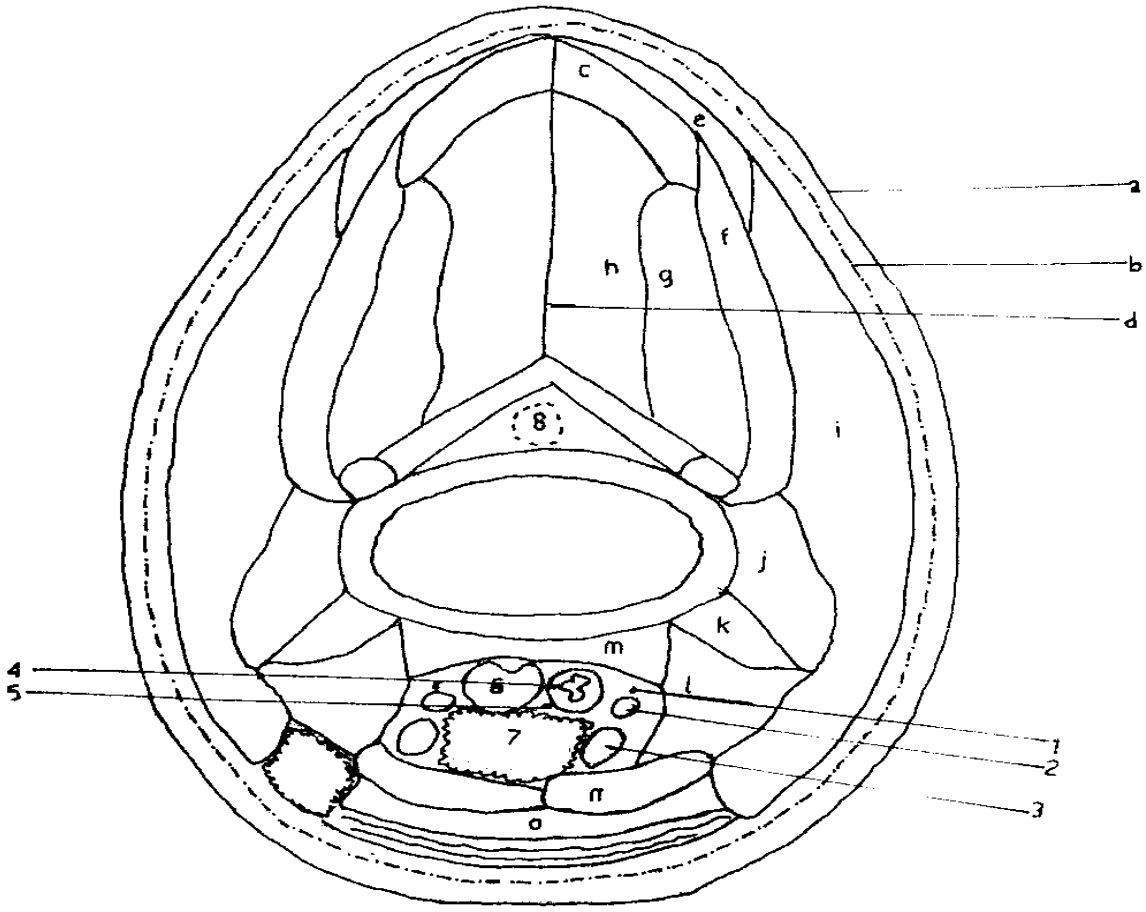
at the level of the 3rd cervical vertebra and the 5th cervical vertebra (figg.4 and 5).
The thoracic part was studied at two cross-sections: at the level of the thoracic inlet (fig. 6) and of the base of the heart (fig. 7).
An abdominal part of the esophagus is absent in the camel fetuses and also in the adult camel.

The pharyngo-esophageal junction (fig. 3):
It is the first part of the esophagus and lies over the larynx. As the table 2 indicates, it is in all developmental stages of the camel the widest part. The diameter is 1.2 mm in the camel fetus of 22 cm CRL and finally 28.34 mm in the adult camel. The esophagus descends from over the larynx to the dorsal aspect of the trachea, forming a slightly dorsally convex cephalo-cervical curvature.
As figure 3 indicates is the initial part of the esophagus directly found over the cricoid cartilage of the larynx. The trachea and the esophagus are surrounded by the pre-tracheal lamina, constituting the deep cervical fascia. Dorsally it is related to a tissue filled space (Septum retropharyngum). The carotic vagina is situated laterally from the esophagus and the retropharyngeal space, containing important structures like the A. carotis communis, V. jugularis interna and the Truncus vagosympathicus. Ventro-

Fig. 3 Cross-section through the neck of a camel fetus with a CRL of 80 cm at the level of the larynx. Cranial view. Schematic representation.

a Cutis (skin)
b Superficial cervical fascia
c Funiculus nuchae
d M. obliquus capitis caudalis
e M. complexus
f M. longissimus capitis
g M. longissimus atlantis
h M. rectus capitis ventralis
i M. omohyoideus
j M. sternomastoideus
k M. sternothyrohyoideus
l M. cricoarytenoideus

1 Truncus vagosympathicus
2 A. carotis communis
3 V. jugularis externa
4 Esophagus
5 Cricoid cartilage of larynx
6 Laryngeal cavity
7 Thymus, cervical lobe
8 Retro-pharyngeal space
9 Ventral arch of atlas
10 Vertebral foramen
11 Spinal cord
12 V. jugularis interna



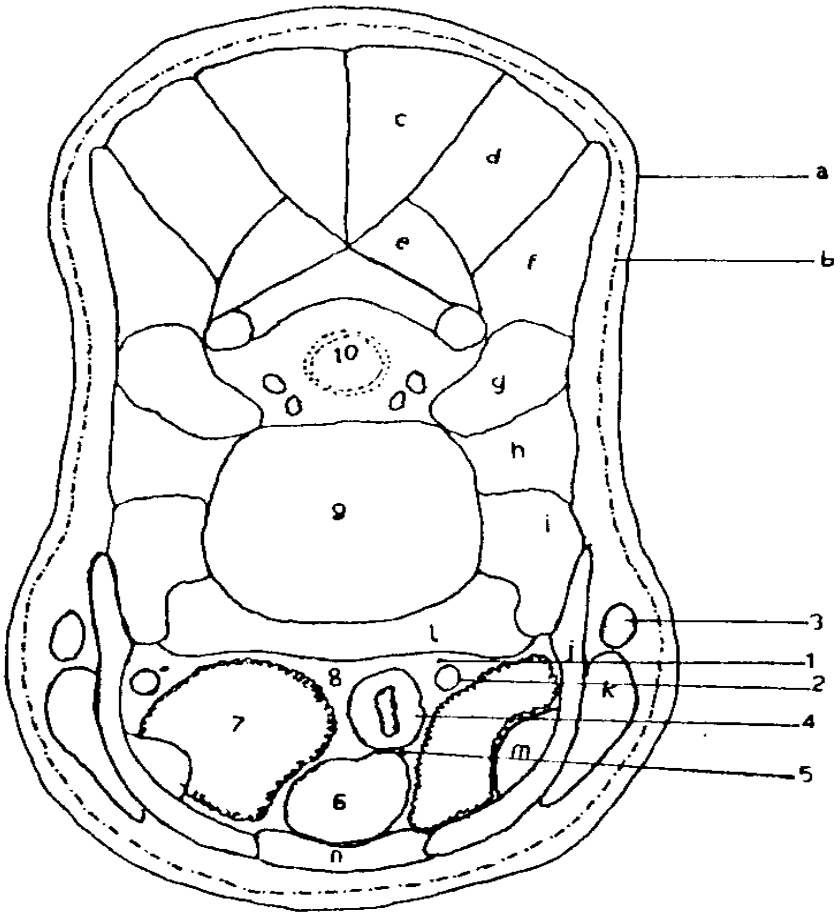
lateral from the esophagus the two cervical lobes of the thymus are found. Laterally from these structures the omo-hyoid muscle separates the external jugular vein from the common carotid artery. Ventrally are the esophagus and the criooid cartilage with the thyroid gland on either side. The sternothyrohyoid and sternomastoid muscles are found also here. The outer layer is formed from the superficial cervical fascia and the thick skin.

The cervical part (Pars cervicalis esophagi) (figg.4 and 5): The cervical part continues the pharyngo-esophageal junction caudally and is a very long part, if compared with the thoracic part of the esophagus or with the cervical part of the other ruminants. Absolutely, the length of the cervical part is developing from 7 cm in the camel fetus with a CRL of 22 cm till 32.3 cm in the camel fetus of CRL 100 cm. In its diameter the cervical part is narrower than the pharyngo-esophageal junction (table 2). This could be observed thoroughly (0.64 mm in camel fetus of CRL 22 cm and 22.6 mm in the adult camel at the level of the middle cervical part and 0.48 mm in the camel fetus of CRL 22 cm to 20.7 mm in the adult camel at the thoracic inlet).
At the level of the third cervical vertebra the esophagus is found dorso-laterally to the trachea. It continues in this course till to the level of sixth cervical vertebra,

Fig. 4 Cross-section through the neck of a camel fetus (CRL 80 cm) at the level of the third cervical vertebra.
Cranial view. Schematic representation.

a Cutis (skin)
b Superficial cervical fascia
c Funiculus nuchae
d M. complexus
e M. multifidus cervicis
f M. longissimus capitis
g M. longissimus atlantis
h Mm. intertransversarii cervicis (Pars dorsalis)
i Mm. intertransversarii cervicis (Pars ventralis)
j M. omohyoideus
k M. sternomastoideus
l M. longus colli (Pars cervicalis)
m M. sternothyroideus
n M. sternohyoideus

1 Truncus vagosympathicus
2 A. carotis communis
3 V. jugularis externa
4 Esophagus
5 Recurrent laryngeal nerve
6 Trachea
7 Thymus, Lobus cervicalis
8 Extension of the retro-pharyngeal space
9 Body of the third cervical vertebra
10 Spinal cord
11 V. jugularis interna



where the trachea deviates to the right side of the median plane and the esophagus to the left side of the trachea. At the thoracic inlet it forms the dorsally concave cervico-thoracic curvature.

The relations of the cervical part of the esophagus are illustrated in the figures 4 and 5.

Dorsally it is related to the retro-pharyngeal space, which is narrower towards the thoracic inlet, prevertebral lamina with M. longus colli at the level of 3rd cervical vertebra, the right and left carotic vagina, the thymus, omohyoid and external jugular vein.

At the level of the fifth cervical vertebra the following relations are found;

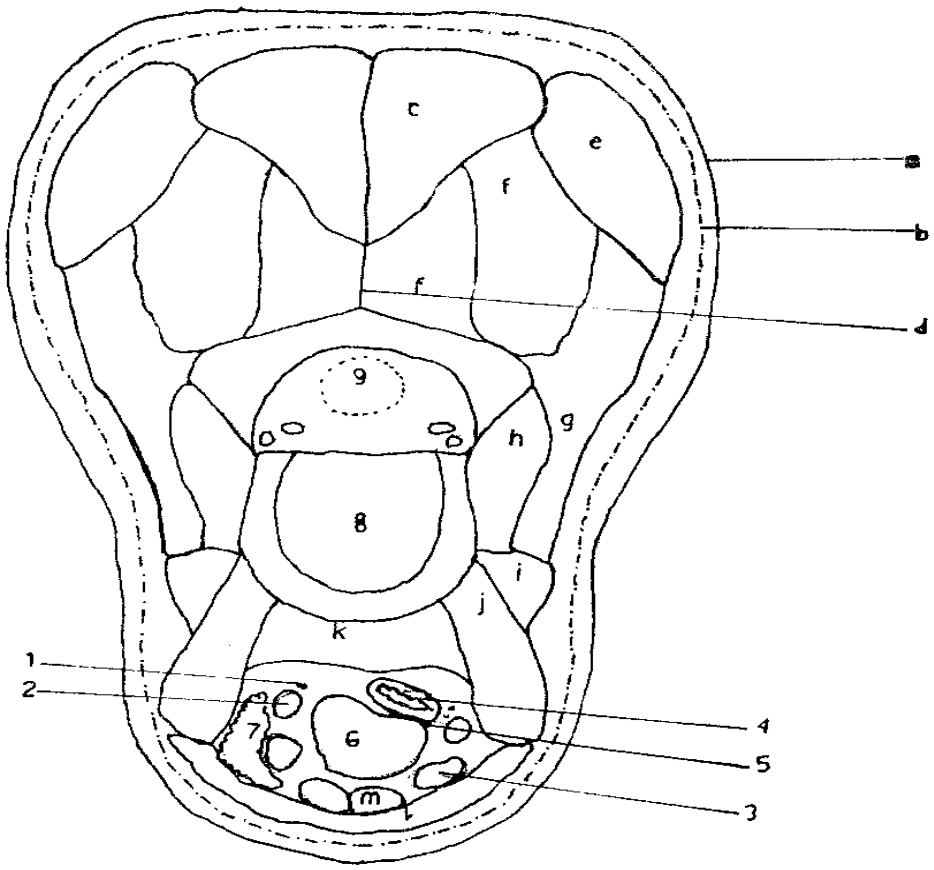
Dorsally the M. longus colli and retro-pharyngeal space, ventro-laterally the trachea, laterally the carotic vagina on both sides (this contains the common carotic artery, the vago-sympathetic trunc and internal jugular vein), ventrally the thymus, sternothyrohyoid, sternomastoid muscle, the superficial cervical fascia and the skin.

The <u>thoracic part (Pars thoracica esophagi)</u> (figg.6 and 7): The thoracic part of the esophagus continues caudally the cervical part and extends from the thoracic inlet cranially till to the Hiatus esophageus of the diaphragm caudally.

Fig. 5 Cross-section through the neck of a camel fetus with a CRL of 10 cm at the level of the fifth cervical vertebra
Cranial view. Schematic representation.

a Cutis (skin)
b Superficial cervical fascia
c Funiculus nuchae
d Lamina nuchae
e M. complexus
f M. multifidus cervicis
g M. longissimus cervicis
h M. serratus ventralis cervicis
i M. scalenus dorsalis
j Mm. intertransversarii cervicis
k M. longus colli
l M. sternomastoideus
m M. sternothyrohyoideus

1 Truncus vagosympathicus
2 A. carotis communis
3 V. jugularis externa
4 Esophagus
5 Recurrent laryngeal nerve
6 Trachea
7 Thymus, cervical lobe
8 Body of the fifth cervical vertebra
9 Spinal cord
10 V. jugularis interna



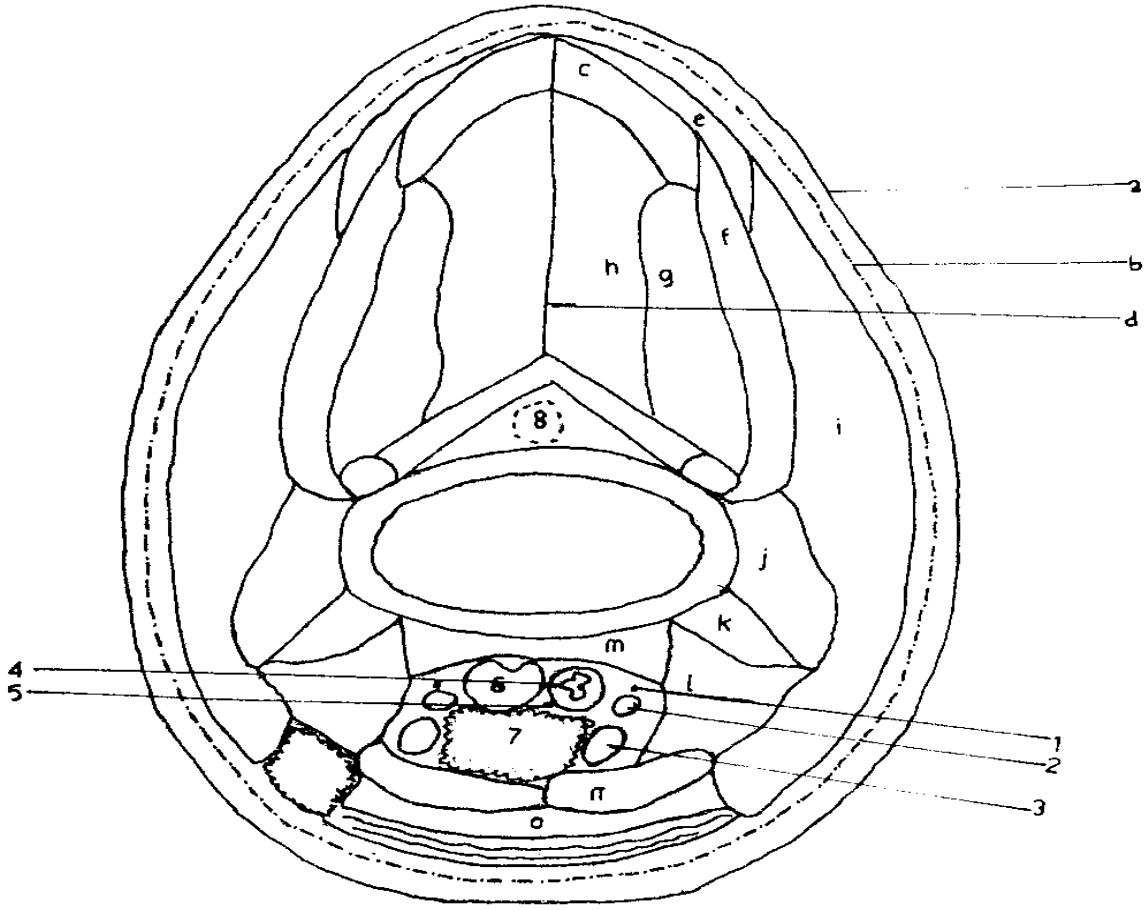
The thoracic part of the esophagus is absolutely shorter than the cervical part (table 1). It measures about 5 cm in the camel fetus of CRL 22 cm and 19.7 cm in the camel fetus of CRL 100 cm. The diameter of the thoracic part of the esophagus (table 2) is somewhat smaller than that of the cervical part, but at the same time the esophageal wall in this part is thicker than in the cervical part. From the thoracic inlet, the esophagus runs caudally. It passes dorsally the cranial, middle and caudal mediastinal space at the base of the heart (level of the fourth or fifth thoracic vertebra). The thoracic part forms the third curvature of the esophagus, which is dorsally convex. The aorta courses at the base of the heart and displaces the esophagus to the right side of the median plane, leaving the base of the heart on the left. The esophagus curves ventrally and caudally to the left of the median plane in the caudal mediastinum, where it enters the esophageal hiatus at the level of tenth thoracic vertebra.
The relations of the thoracic part of the esophagus were found to be the following:

<u>At the level of the thoracic inlet</u> (fig. 6):
<u>Dorsally:</u> The left longus colli muscle.
<u>Latero-ventrally:</u> The left carotic vagina, containing the

Fig. 6 Cross-section through the neck of a camel fetus with a CRL of 80 cm at the level of the thoracic inlet Cranial view. Schematic representation.

a Cutis (skin)
b Superficial cervical fascia
c Funiculus nuchae
d Lamina nuchae
e M. trapezius
f M. serratus ventralis cervicis
g M. complexus
h M. multifidus cervicis
i M. mastoidohumeralis (Pars cleidocervicalis)
j M. longissimus cervicis
k M. scalenus
l Mm. intertransversarii cervicis
m M. longus colli
n M. sternothyrohyoideus
o M. sternomastoideus

1 Truncus vagosympathicus
2 A. carotis communis
3 V. jugularis externa
4 Esophagus
5 Recurrent laryngeal nerve
6 Trachea
7 Thymus, Lobus intermedius
8 Spinal cord
9 V. jugularis interna



common carotid artery, vago-sympathetic trunk and internal jugular vein, external jugular vein.

Ventrally: The thymus, sternomastoid and sternothyrohyoid muscles.

Medially: The trachea.

At the level of base of the heart (5^{th} thoracic vertebra) (fig. 7):

Ventrally: The root of the lung, ventral vagal trunk.

Dorsally: The dorsal vagal trunk. Left side the thoracic aorta. Right side the pulmonary pleura and right lung.

At the level of the Hiatus esophageus:

Dorsally: Truncus vagalis dorsalis and caudal mediastinal lymphnode.

Ventrally: The Truncus vagalis ventralis.

Laterally: The mediastinal pleura of the caudal mediastinum.

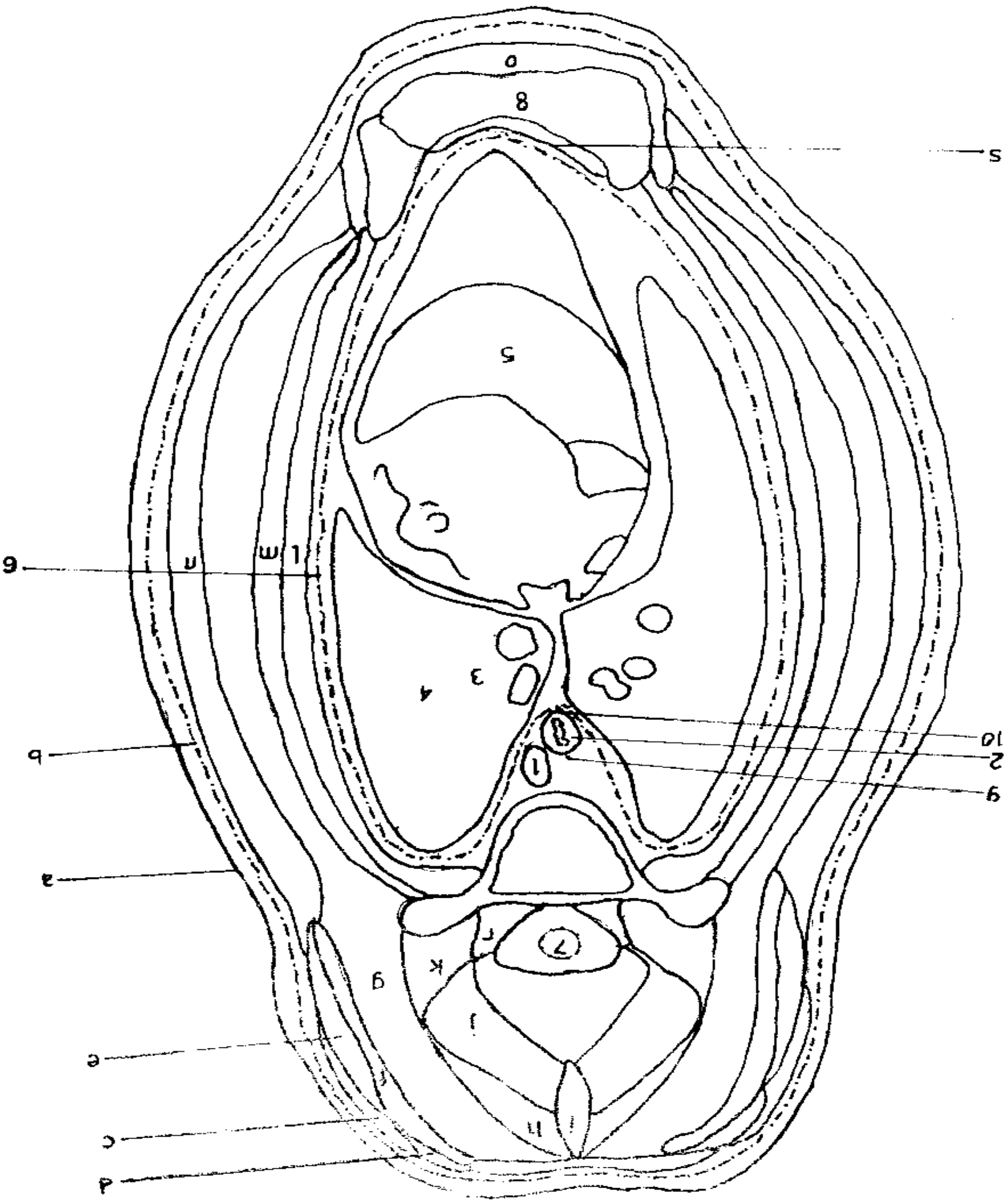
4.2 Lateral dissection:

In the adult camel from our studies we observed the cervical part as being longer than the thoracic part. It measures 115 cm in the cervical part and 60 cm in the thoracic part. Also the diameter increases with age. The widest part of the esophagus is found over the larynx. It measures

Fig. 7 Cross-section through the thorax of a camel fetus with a CRL of 80 cm at the level of the fifth rib. Cranial view. Schematic representation.

a Cutis (skin)
b Fascia trunci superficialis
c M. trapezius
d M. supraspinatus
e M. infraspinatus
f Scapula
g M. serratus ventralis thoracis
h Funiculus nuchae
i Lamina nuchae
j M. complexus
k M. multifidus thoracis
l Fifth rib
m Mm. intercostales externi and interni
n M. latissimus dorsi
o M. pectoralis transversus
p M. longissimus dorsi thoracis
q M. transversus thoracis

1 Aorta thoracica
2 Esophagus
3 Root of the lung
4 Lung
5 Heart
6 Pleura parietalis
7 Spinal cord
8 Sternum
9 Dorsal branch of the vagus
10 Ventral branch of the vagus



here 28.34 mm in the adult camel. After this, the esophagus has nearly the same diameter up to esophageal hiatus (table 2).

The course of the esophagus varies from one part to another. In the cranial third of the neck it is found over the larynx and trachea. In the middle third of the neck from the third up to fifth cervical vertebrae it is found dorso-laterally to the trachea. In the caudal third of the trachea up to the thoracic inlet it is situated left to the median plane at the same time and the trachea right to the median plane. The esophagus continues to the left aspect of the trachea up to the second thoracic vertebra, where it gradually shifts to the dorsal surface of the trachea. There it is found completely on the dorsal aspect of the trachea at the level of fourth thoracic vertebra. It continues over the dorsal aspect of the trachea until the tracheal bifurcation at the level of fifth thoracic vertebrae passes backward in the median plane of the body. At this site the esophagus is in contact with the dorsally bent aortic arch on its left side. There after the esophagus passes backward in the caudal mediastinum and is based to the left side of the median plane towards the esophageal hiatus, which is located in the left part of the diaphragm at the level of tenth rib.

The abdominal part of the esophagus is indistinct.
The esophagus forms three curvatures in its course. The first one at the junction of the esophageal vestibule and the beginning of the esophagus is slightly convex dorsally (cephalo-cervical curvature). The second one is found at the junction of the neck with the trunk, extending from the sixth cervical vertebra till to the second thoracic vertebra. It is concave dorsally. The third curvature is found at the base of the heart, where the aortic arch pushes the esophagus to the right side of the median plane. After this the esophagus crosses the median plane to the left. It forms this curvature, which is dorsally convex. After this it continues its course in the caudal mediastinum to enter the esophageal hiatus.

Relations of the esophagus: In the cranial third of the neck the esophagus is related ventrally to the larynx and the trachea, dorsally to the retro-pharyngeal space, which extends cranially from the pharynx up to the dorsal mediastinum.
Laterally the carotic vagina is found, which contains the common carotid artery, the vago-sympathetic nerve trunk, and internal jugular vein, the thymus and the omohyoid muscle, which separates the external jugular vein from the

carotic vagina, sternomastoid muscle, superficial cervical fascia and the skin.

In the middle third of the neck, from the third up to the fifth cervical vertebra, the esophagus is related ventro-laterally to the trachea and the recurrent laryngeal nerve, dorsally to the longus colli muscle, laterally to the carotic vagina, which contains the common carotid artery and the vago-sympathetic nerve trunk and internal jugular vein, thymus, omohyoid muscle, external jugular vein, sterno-mastoid muscle, superficial cervical fascia and the skin.

At the junction between neck and thorax it is related dorsally to the left longus colli muscle, medially to the trachea and the recurrent laryngeal nerve, ventro-laterally to the carotic vagina, the external jugular vein, ventrally to the thymus, sternomastoid and sternothyrohyoid muscles, superficial cervical fascia and the skin. After this, the esophagus crosses the thoracic inlet, entering the thoracic cavity, where in the cranial mediastinum it is related medially to the trachea, dorsally to the left longus colli muscle, laterally to the vagus nerve trunk, left phrenic nerve, and the left subclavian artery.

In the middle mediastinum, the esophagus is found over the trachea, up to the base of the heart, crossing the right face of the aortic arch. After this it passes in the caudal

mediastinum between the two layers of the mediastinal pleura, where it is related dorsally to the descending aorta and the caudal mediastinal lymph node. Dorsally, it is accompanied by the dorsal branch of the vagus nerve and ventrally by its ventral branch. The esophagus passes the esophageal hiatus to terminate in the stomach.

T a b l e 1

Length of the esophagus and its individual parts

	CRL / year	Total length	Cervical part	Thoracic part
camel fetus	22 cm	12 cm	7.0 cm	5.0 cm
" "	30 cm	15 cm	9.0 cm	6.0 cm
" "	40 cm	23 cm	14.5 cm	8.5 cm
" "	55 cm	26 cm	16.6 cm	9.4 cm
" "	62 cm	33 cm	21.2 cm	11.8 cm
" "	70 cm	36 cm	22.5 cm	13.5 cm
" "	80 cm	41 cm	23.6 cm	17.4 cm
" "	100 cm	52 cm	32.3 cm	19.7 cm
young camel	1.5 year	147 cm	93.5 cm	53.5 cm
adult "	5 years	155 cm	99.5 cm	55.5 cm
" "	6 years	175 cm	115.0 cm	60.0 cm

Table 2

Diameter of the esophagus in its individual portions

(completely isolated, relaxed and not extended esophagus)(formaline fixed)

	CRL / years	Over the larynx	At the middle of the neck	At the thoracic inlet	Over the base of the heart	Just cranial to the hiatus esophageus
camel fetus	22 cm	1.20 mm	0.64 mm	0.48 mm	0.48 mm	0.48 mm
" "	30 cm	2.20 mm	1.60 mm	0.95 mm	0.95 mm	0.95 mm
" "	40 cm	3.18 mm	2.20 mm	1.60 mm	1.60 mm	1.60 mm
" "	55 cm	4.14 mm	2.80 mm	2.20 mm	2.20 mm	2.20 mm
" "	62 cm	5.09 mm	3.50 mm	2.80 mm	2.70 mm	2.80 mm
" "	70 cm	5.70 mm	3.82 mm	3.18 mm	2.80 mm	3.18 mm
" "	80 cm	7.30 mm	4.70 mm	4.14 mm	3.82 mm	3.82 mm
" "	100 cm	9.23 mm	7.00 mm	6.36 mm	5.70 mm	6.05 mm
young camel	1.5 year	20.70 mm	16.87 mm	13.37 mm	13.37 mm	13.69 mm
adult "	5 years	26.40 mm	19.30 mm	15.65 mm	15.30 mm	15.42 mm
" "	6 years	28.34 mm	22.60 mm	20.70 mm	20.38 mm	21.00 mm

5. Histological results

5.1 Histological studies on the individual parts of the esophagus during its ontogenetic development

For matter of convenience the esophagus was divided into the following five portions:

1. pharyngo-esophageal junction,
2. middle cervical part,
3. part at the thoracic inlet,
4. part at the base of the heart,
5. part cranial of the esophageal hiatus.

The description of the results will be laid down in such a manner, that firstly qualitative and quantitative aspects of the individual esophageal portions are considered for all stages and after this the entire esophagus for a certain ontogenetic stage.

5.1.1 Qualitative aspects:

Pharyngo-esophageal junction:

Tunica mucosa:

Lamina epithelialis: In the camel fetus of CRL 2 cm the

Lamina epithelialis consists of two layers of nuclei. The deeper ones are spherical, deep basophilic and densely packed. The superficial ones are oval in shape. The cell walls are indistinct. In the camel fetuses of CRL 13 cm - 75 cm the Lamina epithelialis consists of a superficial layer and a deep layer. The superficial one varies in thickness due to the increasing number of cell layers with increasing age (CRL 13 cm = 4 layers, CRL 25 cm = 4 - 7 layers, CRL 30 cm = 6 - 8 layers, CRL 41 cm = 10 - 12 cell layers, CRL 52 cm = 15 - 20 layers, CRL 64 cm = 15 - 21 layers, CRL 75 cm = 17 - 22 layers).

The cells are polyhedral in shape, with large, spherical or ovoid and centrally located nuclei, containing one or more nucleoli. The cytoplasm appears faintly stained with H&E. The cell walls are distinctly visible (fig. 8) in the camel fetuses of CRL 82 cm. The top layer of cells becomes flattened and the cytoplasm appears pinkish with H&E. In the CRL 95 cm-fetus these layers increase to 3 - 4, correspondingly their nuclei are flattened. Among our studied material firstly in the young camel of 1.5 years of age the keratinization of the top cell layer of the superficial layer is observed, which is made up of 4 - 5 layers. The keratinization process was found to be extremely elaborated in 6 years old adult camels.

Fig.8 Longitudinal section through the pharyngo-esophageal junction of a camel fetus (CRL 25 cm)
H&E stain. Obj.: 10; Ocular 5 :1K

1 Lamina epithelialis
2 Lamina propria mucosae/submucosa
3 Glandulae esophageae in the Lamina propria mucosae/submucosa

Fig. 9 Longitudinal section through the pharyngo-esophageal junction of a camel fetus (CRL 41 cm)
H&E stain. Obj.: 20; Ocular 5 : 1K

1 Lamina epithelialis
2 Lamina propria mucosae/submucosa
3 Glandulae esophageae
4 Excretory duct of a Glandula esophagea

the Lamina propria mucosae/submucosa is filled with many blood vessels (venous plexus in the deeper part of this layer). Gradually the richness of the connective tissue cells is replaced by connective tissue fibers in the camel fetuses of advanced ontogenetic stages (fig. 8). Thus in the young camel there is a much thicker fibrous tissue than in the camel fetus of CRL 95 cm. This layer is characterized by dense irregular connective tissue. The elastic fibers firstly appear in the camel fetus of CRL 82 cm as very delicate ones in the deeper part of this layer and around the esophageal glands. The ontogenetic development of the Lamina propria mucosae/submucosa is not only featured by the increased collagenic and elastic fibers, but also by the elaboration of the papillary body, which is firstly observed by us in post-partum-samples (young camel, 1.5 years of age).

The esophageal glands (Glandulae esophageae):
For the first time they appear in the camel fetus of CRL 25 cm. They are visible as spherical epithelial masses in the Lamina propria mucosae/submucosa (fig. 8). As epithelial buds they project from the esophageal epithelium into the surrounding mesenchymal mass. Solid epithelial strands connect the esophageal epithelium

Fig. 10 Longitudinal section through the pharyngo-esophageal junction of a camel fetus (CRL 52 cm)
VAN GIESON stain. Obj.: 20; Ocular 5 :1K

1 Lamina epithelialis
2 Lamina propria mucosae/submucosa
3 Glandula esophagea
4 Excretory duct of the esophageal gland

with this glandular epithelium. They represent the excretory ducts of the esophageal glands. The glands are evenly distributed around the esophageal lumen. The canalization of the excretory ducts begins at the stage of CRL 30 cm and that of the secretory units in the camel fetus of CRL 41 cm (fig. 9). The canalization progresses with age (fig. 10) till in the camel fetus of CRL 64 cm all excretory ducts and secretory units are completely canalized. At the camel fetus of CRL 82 cm the cell nuclei of the epithelial glandular cells become pushed to the periphery (cellular base), thus taking similarity with mucous glands. The glandular end-pieces show narrow lumina, surrounded by high columnar cells with basally situated nuclei. The excretory ducts are lined by cuboidal to columnar cells, which change into squamous cells at the termination of the duct.

Tunica muscularis:

It is already early developed (camel fetus of CRL 2 cm) and composed of undifferentiated mesenchymal cells with large oval nuclei. In the camel fetus of CRL 25 cm a spiral arrangement of muscle cells becomes already clear. Inside the muscle fibers course longitudinally, but some times circularly. Also the outer layer courses circularly,

but sometimes longitudinally. The two layers are separated by intermuscular connective tissue, which begins to develop in the camel fetus of CRL 41 cm. It is composed of collagenic fibers and elastic fibers (CRL 82 cm). It is rich in blood vessels and nerve plexuses.
The thickness of the Tunica muscularis is increased with the advanced age.

Tunica adventitia:
It is early developed (CRL 13 cm). Firstly it is more cellular, later on more fibrous and rich in blood vessels and nerves. Dense irregular connective tissue fixes the esophagus in its junction with the pharynx to the surrounding structure.

Middle cervical part:

Tunica mucosa:

Lamina epithelialis: Principally it is composed of a superficial and a deep layer (fig. 11). The former one is built up of about 5 layers in the camel fetus of CRL 13 cm. These layers increase with increasing age. The Lamina epithelialis is formed by about 5 - 7 cell layers at the CRL of 25 cm, 7 - 9 layers at the CRL of 30 cm, 9 - 11 layers at the CRL of 41 cm, 12 - 15 layers at the CRL of 52 cm (fig. 12), 15 - 20 layers at the CRL of 64 cm.

Fig. 11 Cross-section through the middle cervical part of the esophagus of a camel fetus (CRL 30 cm)
H&E stain. Obj.: 20; Ocular 5 ; 1K

1 Lamina epithelialis
2 Lamina propria mucosae/submucosa
3 Glandula esophagea
4 Excretory duct of the Glandula esophagea

The cells are polygonal in shape with large, spherical and centrally located nuclei, containing one or more nucleoli. The cytoplasm is faintly stained. The cell boundaries are distinct. In the camel fetus of 82 cm CRL the superficial layer looses its loosely arranged state of large polyhedral cells and is replaced by compressed, solidified, strongly eosinophilic cells. The top layer consists of flattened cells with flattened nuclei (fig. 13). During the fetal development no keratinization of the stratified squamous epithelium in the middle cervical part could be observed. This occurs after birth. Thus, in the young camel of 1.5 years of age the superficial layer is keratinized. Of course, the cornified layer has not the same strength like in adult camel.

The deep layer consists always of one cell layer during the entire ontogenetic development (figg. 11, 12, 13). The cells are columnar with same shaped nuclei, which contain one or two nucleoli. They rest on a basement membrane, which is especially distinctly visible after H&E. The basal cell layer is completely smooth till to the end of the fetal period. After birth, the epithelial peg-formation is introduced by undulating this line in a wide, spacious manner. This is replaced by short intervalled projecting papillae from the Lamina propria in

Fig. 12 Cross section through the middle cervical part of the esophagus of a camel fetus (CRL 52 cm)
H&E stain. Obj.: 10; Ocular 5 : 1K

1 Lamina epithelialis
2 Lamina propria mucosae/submucosa
3 Glandulae esophageae
4 Excretory duct of a Glandula esophagea

adult camel.

Lamina propria mucosae/submucosa:

In all stages of development and also postnatally the Lamina propria mucosae is blended without any line of demarcation with the submucosa (figg. 11, 12, 13).
It is composed of undifferentiated mesenchymal cells in the camel fetus of CRL 2 cm, which differentiate into collagenic fibers and fibroblasts in the camel fetus of CRL 13 cm. The layer near to the Lamina epithelialis is more cellular and less fibrous. The layer is towards the Tunica muscularis more fibrous and very rich in collagenic fibers, which are irregularly arranged with few elastic fibers (for the first time appearing at CRL of 82 cm). Many blood vessels of different size are found in the deeper part of this layer.
The esophageal glands firstly appear in the camel fetus of CRL 25 cm as outgrowths from the Lamina epithelialis resembling those of the pharyngo-esophageal junction, which appear as solid masses from undifferentiated cells with large, rounded, basophilic nuclei. These epithelial outgrowths are evenly distributed around the esophageal lumen. The canalization of the excretory ducts begins in camel fetuses of CRL 41 cm and of the secretory units in those of CRL 52 cm (fig. 12). From CRL 82 cm the

Fig. 13 Cross section through the middle cervical part of the esophagus of a camel fetus (CRL 82 cm)
H&E stain. Obj.: 10; Ocular 5 : 1K

1 Lamina epithelialis
2 Lamina propria mucosae/submucosa
3 Glandulae esophageae
4 Blood vessel

esophageal glands show a mucous appearance (fig. 13). The lumen of the glandular end-pieces are wide, the epithelial cell nuclei are flattened and pushed to the periphery. In the young and adult camels the esophageal glands form a thick layer.

Tunica muscularis:

This is already early developed. In the CRL 13 cm-stage it presents a two-layered Tunica muscularis. The layers are spirally arranged. In the following stages of the ontogenetic development the increase in thickness is relatively easy to recognize, but the complicated spiral course is maintained. Sometimes the inner layer is longitudinal and the outer one circular and vice versa. The VAN GIESON-stain elucidates clearly that both are separated by intermuscular connective tissue enriched by blood vessels and nerves.

Tunica adventitia:

It is structured from loose connective tissue, anchoring the esophagus to the neighbouring structures. Collagenic and elastic fibers form a network, containing a lot of nutrient structures as blood vessels and nerves. It is less cellular than the Lamina propria mucosae/submucosa.

Part at the thoracic inlet:

Tunica mucosa:

Lamina epithelialis:

The Lamina epithelialis is thicker than in the middle cervical part. Principally it is composed of a superficial layer and a deep layer (fig. 14). The former one consists of 4 - 6 layers of large polyhedral cells with pale, pinkish cytoplasm and more or less centrally disposed nuclei at the stage of 13 cm CRL. The same is practically to observe in camel fetuses of 25 cm (fig. 15) and 30 cm CRL, where one or two layers have been added to the former one. A considerable change is to state from CRL 41 cm in comparison to the previous fetal stage. The Lamina epithelialis is now relatively thick (8 - 12 cell layers). This push continues to the following stages. In fetuses of CRL 52 cm the superficial layer of the Lamina epithelialis comprises now 15 - 17 cell layers in thickness (fig. 16). The 64 cm CRL-fetus shows a tremendous increase of the superficial layer, which is found to be of 15 - 20 cell layers. In the 82 cm CRL-fetus the superficial layer solidifieds strongly and the cells are eosinophilically stained. The top layer, about 2 cells

Fig. 14 Cross section through the esophagus at the thoracic inlet of a camel fetus (CRL 13 cm)
H&E stain. Obj.: 10; Ocular 5 : 1K

1 Lamina epithelialis
2 Lamina propria mucosae/submucosa
3 Tunica muscularis

basophilic nuclei. These flattened cells increase to about 4 cell layers in thickness at CRL 95 cm-stage. During the prenatal developmental stages no keratinization of the stratified squamous epithelium could be observed. This occurs after birth. Thus, in the young camel, 1.5 years of age, the superficial layer is keratinized and comprises only four cell layers of flattened cells with shrunken, darkely stained, pyknotic nuclei. The Stratum corneum is contrasting in colour to the other, distally following layers (fig. 17). The deep layer consists of one layer of densely packed cuboidal to columnar cells, containing large, oval, basophilic nuclei.

Lamina propria mucosae/submucosa:

There is a fusion between the Lamina propria mucosae and the submucosa in all fetal developmental stages and also after birth (figg. 14, 15, 16, 17). It is composed mainly from collagenic fibers, which become more denser with increasing age, and elastic fibers, for the first time appearing at CRL 82 cm as very delicate fibers, concentrated in the deep part of this layer and around the esophageal glands. These fibers form a dense irregular connective tissue, which is more cellular near the basement membrane and highly vascular towards the Tunica muscularis.

Fig. 15 Cross section through the esophagus at the thoracic inlet of a camel fetus (CRL 25 cm)
H&E stain. Obj.: 20; Ocular 5 : 1K

1 Lamina epithelialis
2 Lamina propria mucosae/submucosa
3 Tunica muscularis
4 Glandula esophagea

Fig. 16 Cross section through the esophagus at the thoracic inlet of a camel fetus (CRL 52 cm)
H&E stain: Obj.: 20; Ocular 5 : 1K

1 Lamina epithelialis
2 Lamina propria mucosae/submucosa
3 Glandula esophagea
4 Excretory duct of a Glandula esophagea

The esophageal glands firstly appear at CRL 25 cm (fig. 15) as spherical solid masses among undifferentiated mesenchymal cells, which are still connected with the Lamina epithelialis by a strip of solid cells, representing the excretory ducts of the esophageal glands. They are evenly distributed around the lumen of the esophagus. These solid masses increase in size and begin to be canalized at CRL 41 cm-stage. The canalization increasss with advancing age (fig. 16). Till a CRL of 64 cm all the excretory ducts and secretory units are completely canalized. At the CRL 82 cm-stage the esophageal glands show a mucous appearance. Where the lumen of the glandular end-pieces are wide, the epithelial cell nuclei are flattened and pushed to the base of the cells. After birth, in the young camel of 1.5 years of age (fig. 17) and the adult camel, 6 years of age, these glands are found in the form of clusters occupying more than the half of this layer, extending towards the Tunica muscularis.

Tunica muscularis:

It is already early developed as seen in the pharyngo-esophageal junction and middle cervical part. Thus, the two layers of smooth muscle cells at the CRL 25 cm-stage are spirally arranged. The inner one runs longitudinally,

Fig. 17 Longitudinal section through the esophagus at thoracic inlet of an adult camel (6 years of age). VAN GIESON stain. Obj.: 3.2; Ocular 5 : 1K

1 Lamina epithelialis
2 Lamina propria mucosae/submucosa
3 Tunica muscularis
4 Glandulae esophageae

the outer one circularly and vice versa. At the CRL 82 cm-stage the smooth muscle cells change into the striated muscle fibers with the same spiral arrangement. The inter-muscular connective tissue begins to be developed at the CRL 41 cm-stage and is composed mainly from collagenic and elastic fibers (appear for the first time at the CRL 82 cm-stage). It contains a great number of blood vessels and nerves.

Tunica adventitia:

It is made up of loose connective tissue, containing collagenic and elastic fibers with a lot of nutrient structures (blood vessels and nerves). It is less cellular than the Lamina propria mucosae/submucosa.

Part over the base of the heart:

Tunica mucosa:

Lamina epithelialis:

It is made up of two layers, a superficial and deep one (fig. 18). The superficial one increases in thickness with increasing age. In camel fetuses of a CRL of 13 cm it consists of 5 - 6 layers of polyhedral cells, the cytoplasm of which is light and the nuclei are mostly

Fig. 18 Cross section through the thoracic part of the esophagus (at the base of the heart) of a camel fetus (CRL 25 cm).
H&E stain. Obj.: 20; Ocular 5 ; 1K

1 Lamina epithelialis
2 Lamina propria mucosae/submucosa
3 Tunica muscularis
4 Glandulae esophageae

spherical, basophilic and centrally located. The cell walls are distinct. At the CRL 25 cm-stage the Lamina epithelialis is roughly the same and starts then to increase. Thus at the stage of CRL 30 cm it consists already of 7 - 9 layers, at the CRL of 41 cm of 10 - 12 cell layers, and at the stage of CRL 52 cm of about 15 - 20 layers (fig. 19). The structure of the polyhedral cells is - lightmicroscopically seen - unchanged to the stage of 64 cm CRL. After this, the large polyhedral cells become rearranged. This rearrangement includes firstly a more proximo-distal distention of them and secondly decrease in size, due to the greater number of cells (CRL 75 cm). In the camel fetuses of CRL 82 cm the cells of the superficial layer of the Lamina epithelialis are clearly smaller and more densely packed. The top layer cells are now flattened, but no symptoms of keratinization could be observed, even not at time of birth (CRL 95 cm). The upper three cell layers contain flattened nuclei (fig. 20). They become cornified in the young camel of 1.5 years of age. The Stratum corneum is here relatively strong in the adult camel. The cells of it contain very small, thin, fusiform or rod-like and extremely pyknotic nuclei. The cornified layer comprises about 6 - 8 layers. The deep layer of the Lamina epithelialis is formed by

Fig. 19 Cross section through the thoracic part of the esophagus (at the level of the base of the heart) of a camel fetus (CRL 64 cm).
VAN GIESON stain. Obj.: 20; Ocular 5 : 1K

1 Lamina epithelialis
2 Lamina propria mucosae/submucosa
3 Glandulae esophageae
4 Excretory duct of the Glandulae esophageae

cuboidal and columnar cells with spherical or columnar nuclei, arranged in one row. This gets its first alteration postnatally. First symptoms of a spacious undulation could be observed in the young camel of 1.5 years of age, also a distinct papillary body formation.

Lamina propria mucosae/submucosa:

In all stages of the fetal development and postnatal stages the Lamina propria mucosae is blended with the submucosa (fig. 18). The common Lamina propria mucosae/ submucosa is in general quite cellular, but still more distinct in the areas related to the epithelium. It gets more fibrous peripherally. It is composed mainly from collagenic fibers, which run in an irregular direction (fig. 20), and elastic fibers (firstly seen at CRL 82 cm). They are condensed in the deeper part of this layer and arranged around the esophageal glands. Also in the deeper part of this layer a great number of blood vessels of different calibers are found.

Primordia of the esophageal glands firstly appear at a CRL of 25 cm (fig. 18) as spherical solid masses and solid epithelial buds among undifferentiated mesenchymal cells. These solid masses begin to be canalized at a stage of CRL 41 cm. The canalization of both, excretory

Fig. 20 **Cross section through the thoracic part of the esophagus (at the base of the heart) of a camel fetus (CRL 95 cm)**

H&E stain. Obj.: 10; Ocular 5 : 1K

1 Lamina epithelialis

2 Lamina propria mucosae/submucosa

3 Glandulae esophageae

ducts and secretory end-pieces is finished at the stage of CRL 64 cm (fig. 19). The glands show the character of mucous glands at the CRL 75 cm-stage. The lumina of the glandular end-pieces are moderately wide and the epithelial cell nuclei are pushed to the periphery (fig. 20). The excretory ducts are lined by a layer of cuboidal cells, which change into stratified epithelium at the termination of the duct. In the young and adult camels these glands occupy about the half of this layer, extending towards the Tunica muscularis.

Tunica muscularis:

It is already early developed. At the CRL 2 cm-stage it is observed as undifferentiated mesenchymal cells. After this at the stage of CRL 13 cm they differentiate into two layers. The inner one is the longitudinal one, the outer, the circular one. But this changes more often in the entire course, showing a spiral arrangement. The intermuscular connective tissue is well developed at the CRL 52 cm-stage and filled with blood vessels and nerve plexuses.

Tunica adventitia:

At the CRL 2 cm-stage it is not so early developed as the Lamina epithelialis, Lamina propria mucosae/submucosa and Tunica muscularis. For the first time it appears at the CRL 13 cm-stage as very fine collagenic fibers. After this they increase with advanced age and form a loose connective tissue with many blood vessels and nerve plexuses, covered by one layer of mesothelium.

Thoracic part (cranial of the esophageal hiatus)

Tunica mucosa:

Lamina epithelialis:

The Lamina epithelialis is thicker than that of the cervical part. Principally it is composed of a superficial layer and a deep layer (fig. 21). The former one is built up by 4 - 5 layers of large, polyhedral cells with a pale pinkish cytoplasm and centrally situated nuclei at the stage of 13 CRL. The same is practically to observe in camel fetuses of CRL 25 cm. Only one layer has been added to the former ones. A considerable change is to state from a CRL of 41 cm in comparison to the previous fetal stages. The Lamina epithelialis is composed of 9 - 11 cell layers. This push continues in the following

Fig. 21 Cross section through the thoracic part of the esophagus (just infront of the esophageal hiatus) of a camel fetus (CRL 30 cm).
VAN GIESON stain. Obj.: 20; Ocular 5 : 1K

1 Lamina epithelialis
2 Lamina propria mucosae/submucosa
3 Tunica muscularis
4 Glandula esophagea

stages (CRL of 64 cm). The superficial layer of the Lamina epithelialis comprises 15 - 20 layers in thickness (fig. 22) at the stage of CRL 75 cm. The superficial layer becomes compressed and the upper 4 layers flattened with flattened nuclei and more eosinophilic cytoplasm. During the fetal development no keratinization of the stratified squamous epithelium could be observed. This occurs after birth. Thus, in the young camel of 1.5 years of age the superficial layer is keratinized. It comprises about 3 - 4 cell layers of flattened cells with shrunken, darkly stained pyknotic cell nuclei (fig. 23) (after VAN GIESON). It contrasts with a more brownish colour from the Strata granulosum and spinosum.

The deep layer consists always of one cell layer during the entire phase of the ontogenetic development. The cells are columnar in shape with oval deep basophilic nuclei. They rest on a basement membrane. The basal cell layer is completely smooth till to the end of the fetal period. After birth the connective tissue papillae of the Lamina propria are invading and wave by this, this line in a wide spacious manner (fig. 23).

Fig. 22 Cross section through the thoracic part of the esophagus (just infront of the esophageal hiatus) of a camel fetus (CRL 64 cm).
H&E stain. Obj.: 10; Ocular 5 : 1K

1 Lamina epithelialis
2 Lamina propria mucosae
3 Lamina muscularis mucosae
4 Tela submucosa
5 Glandulae esophageae

Lamina propria mucosae:

In the early fetal stages, investigated by us, a Lamina muscularis mucosae was absent and the Lamina propria mucosae blending with the submucosa without any line of demarcation (fig. 21). The common Lamina propria mucosae/ submucosa is more cellular near to the epithelium and more fibrous near to the Tunica muscularis. Glandular primordia were for the first time observed at a CRL of 25 cm. After this, at the CRL of 64 cm the Lamina muscularis mucosae occurs (fig. 22). The only excretory duct of an esophageal gland is found in this layer. It is composed mainly by collagenic fibers and few elastic fibers (for the first time it appeared at CRL 82 cm).

Lamina muscularis mucosae:

For the first time it was indicated at the stage of 64 cm CRL (fig. 22). Among the numerous connective tissue cells and connective tissue fibers few smooth muscle cells were developing and became longitudinally arranged to form isolated bands. In the young and adult camel they are interrupted by a lot of the esophageal glands (fig. 23).

Fig. 23 Longitudinal section through the thoracic part of the esophagus (just infront of the esophageal hiatus) of a young camel (1.5 years of age).
H&E stain. Obj.: 3.2; Ocular 5 : 1K

1 Lamina epithelialis
2 Lamina propria mucosae
3 Lamina muscularis mucosae
4 Tela submucosa
5 Glandulae esophageae
6 Tunica muscularis

Tela submucosa:

A separated Tela submucosa is present from the fetal stage of CRL 64 cm. Prior to this, only a common Lamina propria mucosae/submucosa could be observed. It is less cellular than the Lamina propria mucosae, but highly vascular and contains more collagenous and elastic fibers (for the first time observed at CRL 82 cm). It is thicker than both, the Lamina propria and Lamina muscularis mucosae. In this layer the esophageal glandsare found, which are evenly distributed around the lumen of the esophagus. They show the character of mucous glands (fig. 24). In the adult camel we observed these glands in form of a cluster, occupying nearly the whole layer and resting on the Tunica muscularis. The excretory ducts penetrate the Lamina muscularis mucosa to open in the esophageal lumen.

Tunica muscularis:

It is already early developed, long before the Lamina muscularis mucosae makes it appearance. It is composed of two layers, which are spirally arranged. The inner layer is longitudinal in some parts, and circular in others and vice versa. During the early developmental stages is

Fig. 24 Longitudinal section of the esophagus of an adult camel showing the typical mucous glands of the esophagus
H&E stain. Obj.: 40; Ocular 5 : 1K

the outer layer composed of smooth muscle cells. Later on (CRL 75 cm) it changes into striated muscle fibers. The intermuscular connective tissue is well developed, also in the late stage of the development containing many blood vessels and nerve plexuses.

Tunica adventitia:

It is composed of loose connective tissue, with many blood vessels and nervs, but less cellular than the Lamina propria mucosae/submucosa.

5.1.2 Quantitative aspects

The present measurements revealed some interesting facts, which are explained in the following tables and figures. The individual layers of the esophageal wall have a clear and straight forward development. The quantitative development of the Lamina epithelialis differs only insignificantly in the individual parts of the esophagus. In all parts it begins somewhat slow, continues in this manner till birth and speeds up in postnatal subjects.
The thoracic part has often a thick Lamina epithelialis.

The growth of the Lamina propria mucosae/submucosa increases also in thickness with age.
The Tunica muscularis develops relatively slow from CRL 2 cm to CRL 25 cm. After this, the growth rate increases significantly. It is always thickest in the thoracic part at the level of the base of the heart.

Quantitative development of the esophagus in camel (absolute)

Pharyngo-esophageal junction

camel fetus CRL	Lamina epithelialis	Lamina propria mucosae/ submucosa	Tunica muscularis	Tunica adventitia
2 cm	18.25 µm	45.20 µm	23.60 µm	-
13 cm	27.12 µm	61.02 µm	33.90 µm	6.78 µm
25 cm	45.40 µm	150.86 µm	177.38 µm	44.07 µm
30 cm	47.20 µm	187.42 µm	273.63 µm	41.60 µm
41 cm	63.28 µm	196.62 µm	370.64 µm	30.51 µm
52 cm	76.76 µm	277.98 µm	402.28 µm	39.51 µm
64 cm	119.78 µm	400.02 µm	589.86 µm	151.42 µm
75 cm	144.08 µm	456.52 um	811.34 µm	165.38 µm
82 cm	166.56 µm	540.14 µm	854.28 µm	192.78 µm
95 cm	180,80 µm	562.00 µm	876.88 µm	189.84 µm
young camel (1.5 years)	219.22 µm	849.76 µm	1482.56 um	216.96 µm
adult camel (6 years)	230.52 µm	1134.52 µm	1683.70 µm	235.04 µm

Table 4

Quantitative development of the esophegus in camel (absolute)

Middle cervical part

camel fetus CRL	Lamina epithelialis	Lamina propria mucosae/ submucosa	Tunica muscularis	Tunica adventitia
2 cm	18.25 µm	45.20 µm	23.60 µm	-
13 cm	42.94 um	67.80 µm	47.46 µm	11.30 um
25 cm	42.44 µm	110.74 µm	137.86 µm	44.07 µm
30 cm	56.50 µm	172.92 um	230.50 µm	37.20 µm
41 cm	70.05 um	212.44 µm	284.76 µm	42.94 µm
52 cm	92.66 µm	327.00 µm	334.48 µm	43.72 µm
64 cm	117.52 µm	372.90 µm	641.84 um	119.78 µm
75 cm	192.22 µm	436.18 µm	822.64 µm	126.22 µm
82 cm	131.08 µm	494.20 µm	904.00 µm	169.50 µm
95 cm	189.84 µm	574.04 µm	919.82 µm	176.28 µm
young camel (1.5 years)	221.48 µm	985.36 µm	1579.74 µm	221.48 µm
adult camel (6 years)	248.60 µm	1313.06 µm	1835.12 µm	227.84 µm

Table 5

Quantitative development of the esophagus in camel (absolute)

Thoracic inlet

camel fetus CRL	Lamina epithelialis	Lamina propria mucosae/ submucosa	Tunica muscularis	Tunica adventitia
2 cm	18.25 µm	45.20 µm	23.60 µm	-
13 cm	37.29 µm	56.50 µm	36.16 µm	11.30 µm
25 cm	56.50 µm	126.56 µm	162.73 µm	39.55 µm
30 cm	59.20 µm	158.20 µm	214.70 µm	33.90 µm
41 cm	74.58 um	187.62 µm	297.98 µm	46.33 µm
52 cm	115.26 µm	372.90 µm	485.90 µm	68.93 µm
64 cm	126.59 µm	386.12 µm	723.20 µm	196.50 µm
75 cm	132.04 µm	391.54 µm	767.00 µm	170.74 µm
82 cm	137.08 µm	494.94 µm	797.78 µm	197.50 µm
95 cm	183.06 µm	664.44 µm	908.52 µm	183.06 µm
young camel (1.5 years)	235.04 µm	815.86 µm	1600.08 µm	207.92 µm
adult camel (6 years)	316.96 µm	1080.00 µm	1952.64 µm	226.00 µm

Table 6

Quantitative development of the esophagus in camel (absolute)

Thoracic part at the base of the heart

camel fetus CRL	Lamina epithelialis	Lamina propria mucosae/ submucosa	Tunica muscularis	Tunica adventitia
2 cm	18.25 µm	45.20 µm	23.60 µm	-
13 cm	39.35 µm	50.85 µm	39.55 µm	16.95 µm
25 cm	67.80 µm	117.52 µm	174.02 µm	40.68 µm
30 cm	73.32 µm	124.30 µm	233.50 µm	43.90 µm
41 cm	94.92 µm	183.06 µm	379.68 µm	61.02 µm
52 cm	155.94 µm	250.86 µm	587.60 µm	65.54 µm
64 cm	195.66 µm	440.70 µm	804.00 µm	111.42 µm
75 cm	204.02 µm	476.66 µm	880.82 µm	118.88 µm
82 cm	229.50 µm	598.90 µm	1107.40 µm	122.04 µm
95 cm	239.56 µm	685.92 µm	1211.36 µm	169.50 µm
young camel (1.5 years)	248.60 µm	904.00 µm	1638.50 µm	221.48 µm
adult camel (6 years)	400.02 µm	1274.64 µm	1968.46 µm	250.85 µm

Table 7

Quantitative development of the esophagus in camel (absolute)

Thoracic part (cranial of the esophageal hiatus)

Camel fetus CRL	Lamina epithelialis	Lamina propria mucosae/submucosa			Tunica muscularis	Tunica adventitia
2 cm	18.25 µm	45.50 µm			23.60 µm	-
13 cm	36.16 µm	55.37 µm			39.55 µm	14.69 µm
25 cm	54.24 µm	135.60 µm			198.14 µm	27.12 µm
30 cm	67.80 µm	172.00 µm			282.50 µm	28.20 µm
41 cm	99.44 µm	187.85 µm			336.00 µm	41.81 µm
52 cm	147.58 µm	404.54 µm			531.10 µm	58.76 µm
		Lamina propria mucosae	Lamina muscularis mucosae	Tela submucosa		
64 cm	176.82 µm	119.74 µm	94.92 µm	207.88 µm	693.82 µm	128.82 µm
75 cm	193.34 µm	149.72 µm	102.32 µm	215.66 µm	719.24 µm	132.04 µm
82 cm	216.46 µm	178.54 µm	128.82 µm	372.90 µm	1107.40 µm	147.52 µm
95 cm	282.50 µm	194.04 µm	137.02 µm	392.22 µm	1229.44 µm	187.16 µm
young camel (1.5 years)	339.56 µm	268.25 µm	139.20 µm	527.25 µm	1821.56 µm	235.04 µm
adult camel (6 years)	389.09 µm	408.67 µm	153.13 µm	788.04 µm	1919.30 µm	244.08 µm

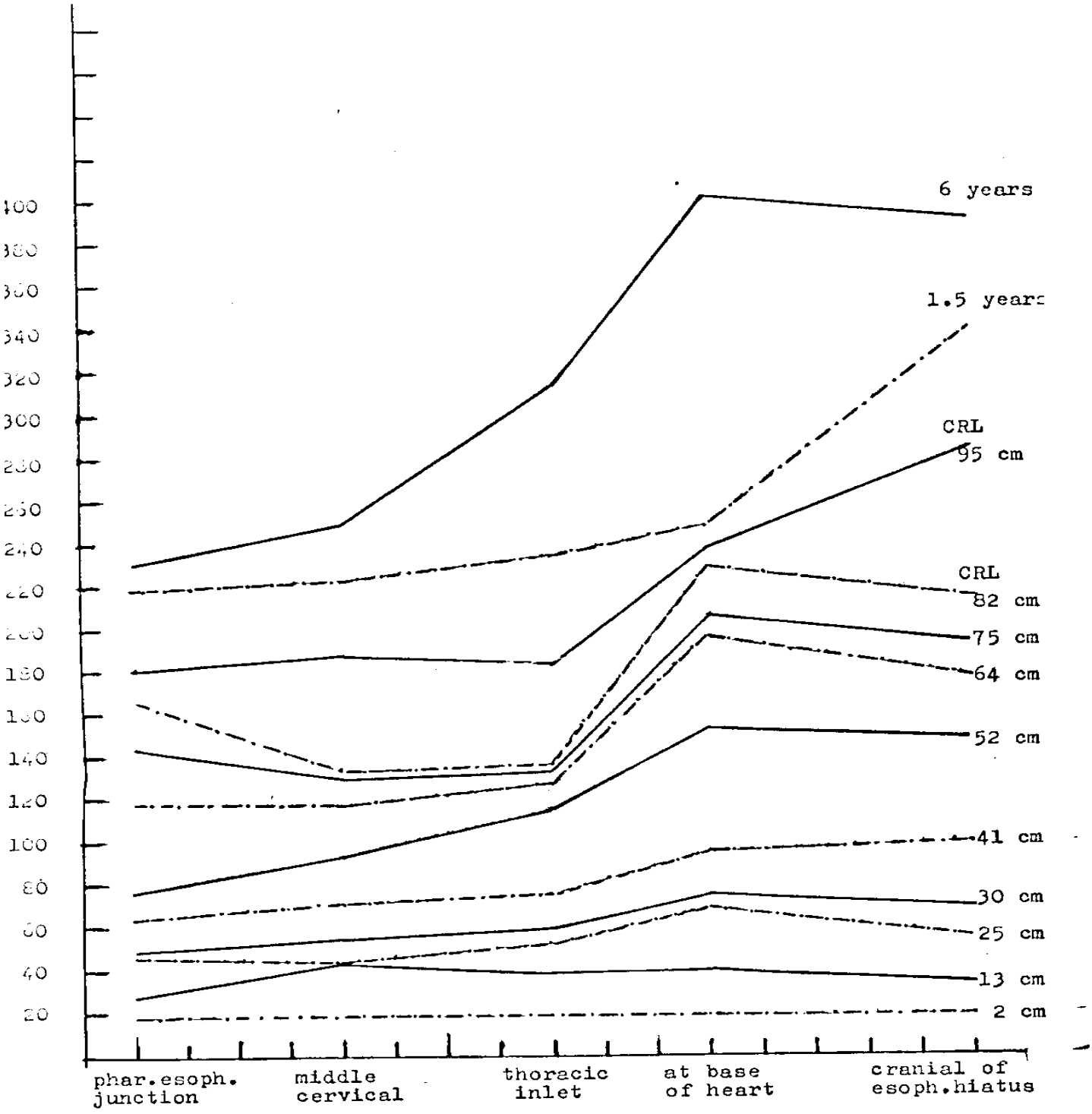


Fig. 34 Lamina epithelialis

in the individual fetuses resp. postnates

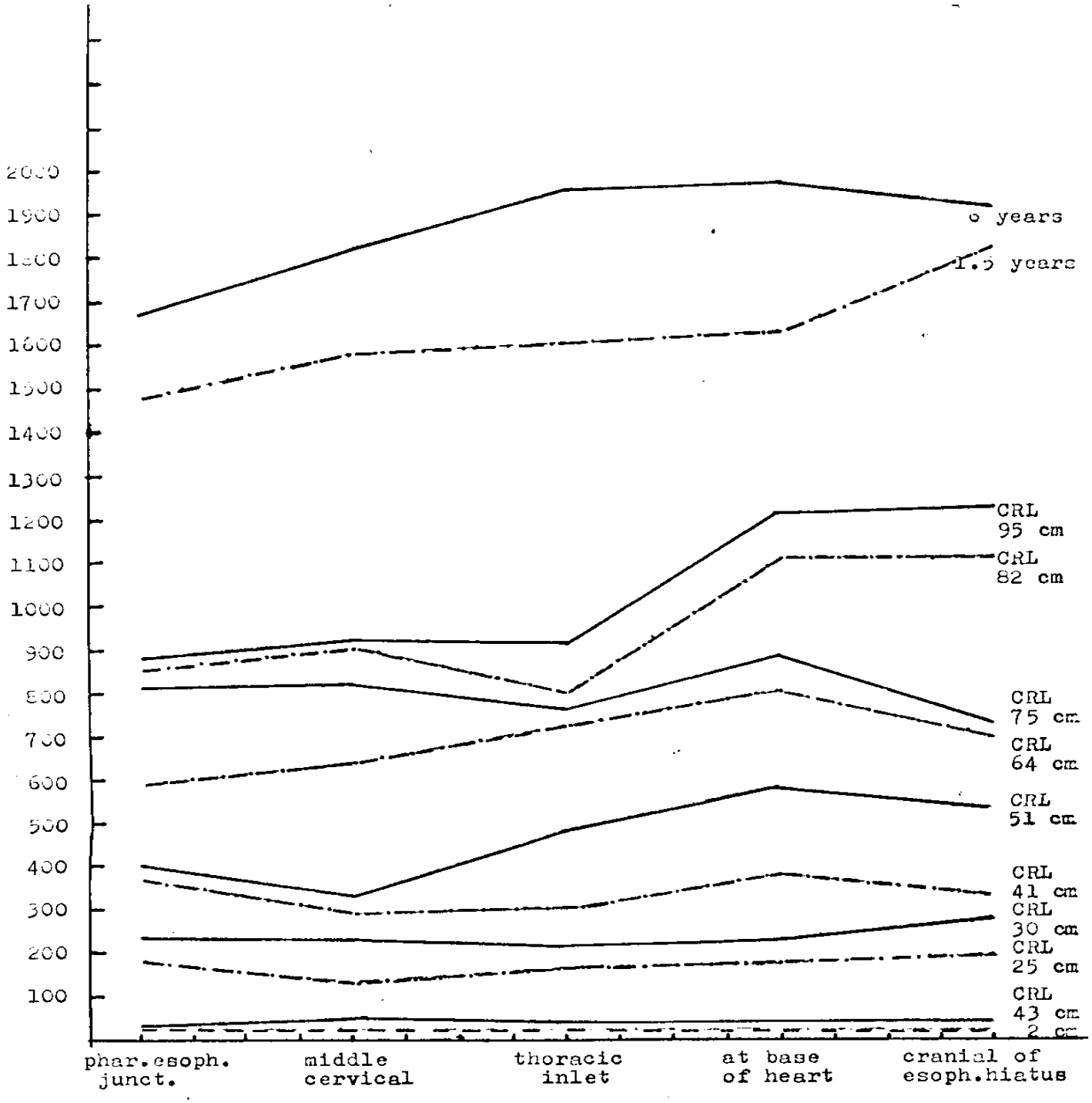


Fig. 35 Tunica muscularis

in the individual fetuses resp. postnates

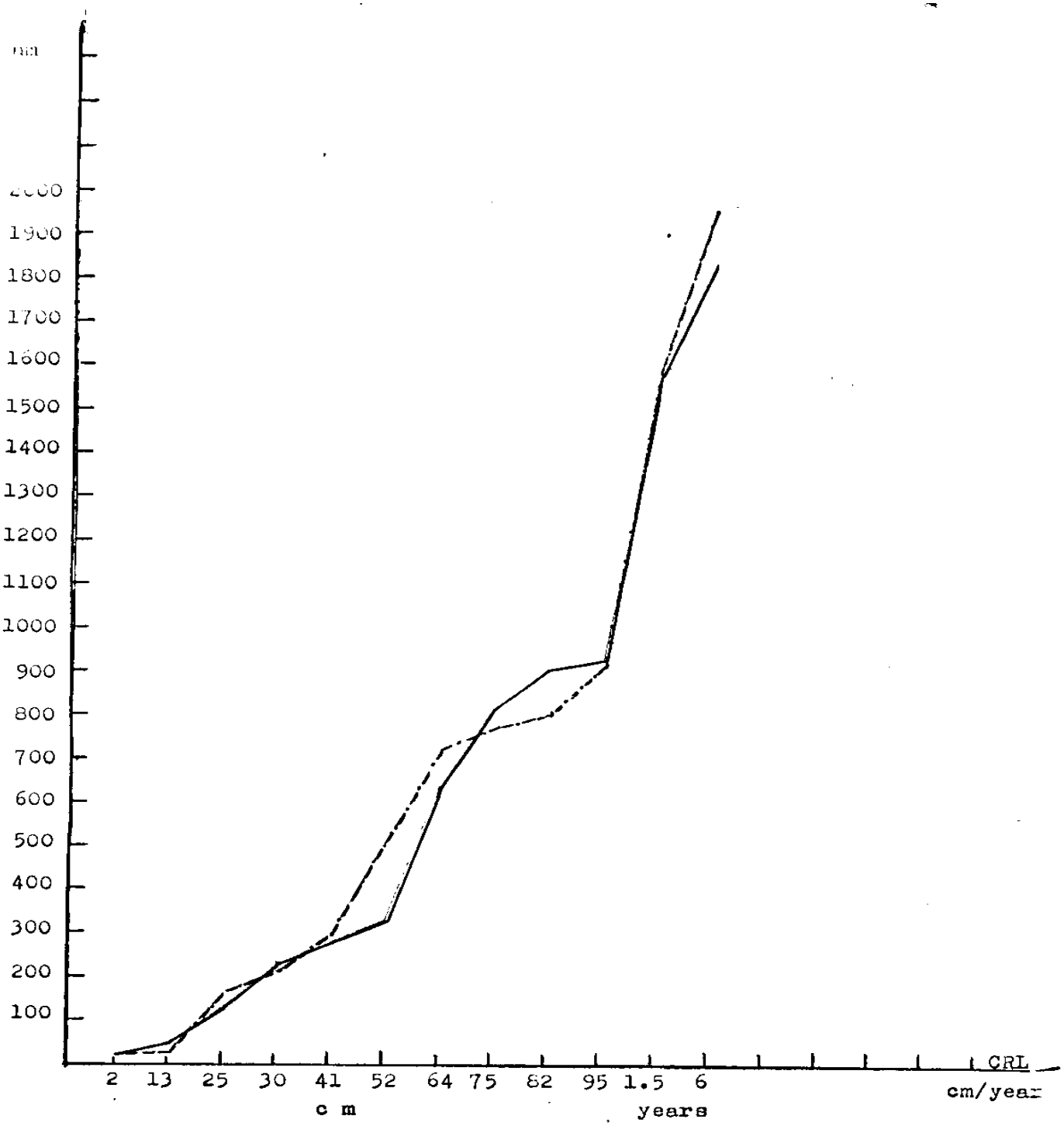


Fig. 32 Tunica muscularis

——— middle cervical part

-.- thoracic inlet

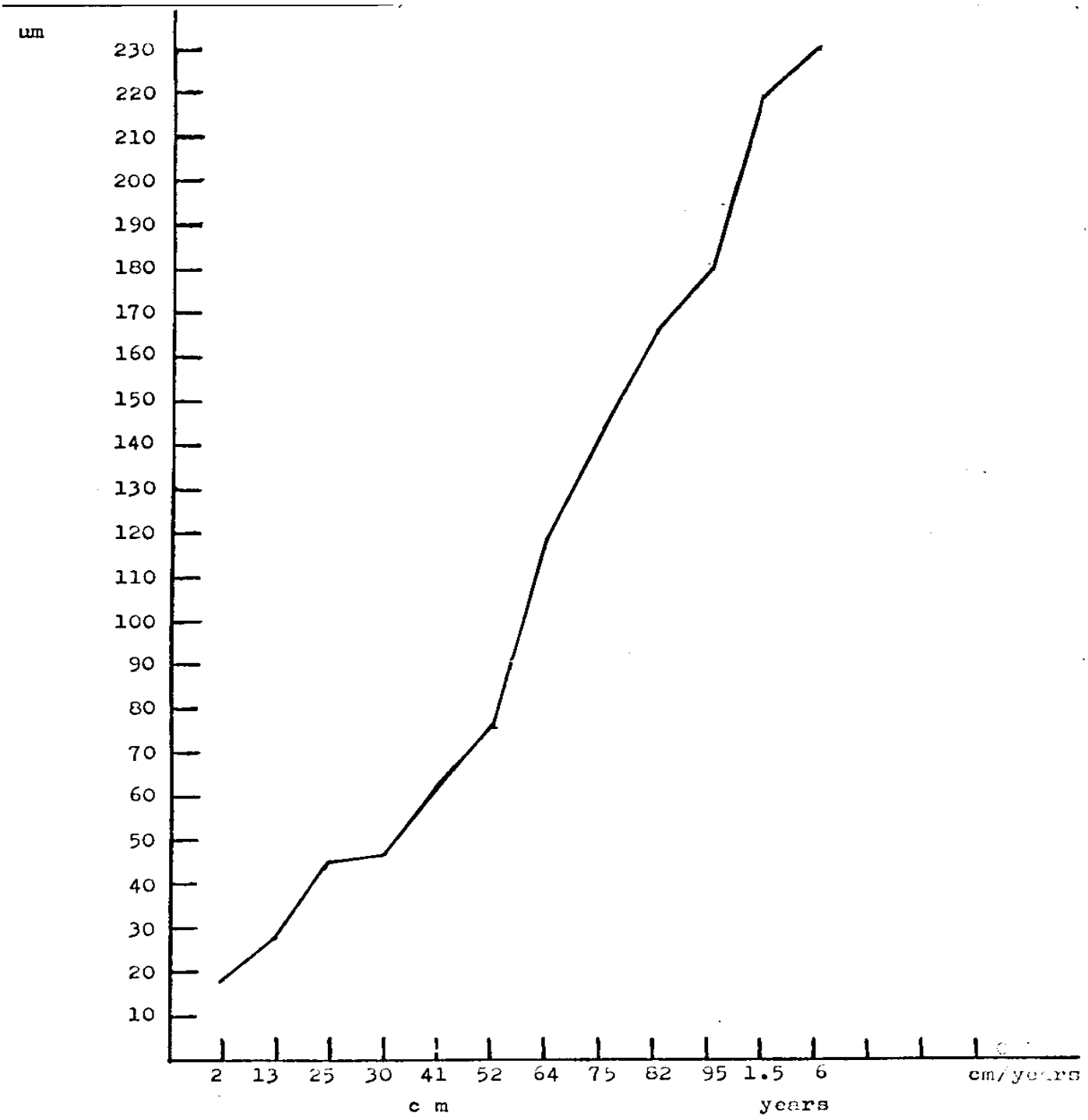


Fig. 25 Lamina epithelialis,
pharyngo-oesophageal junction

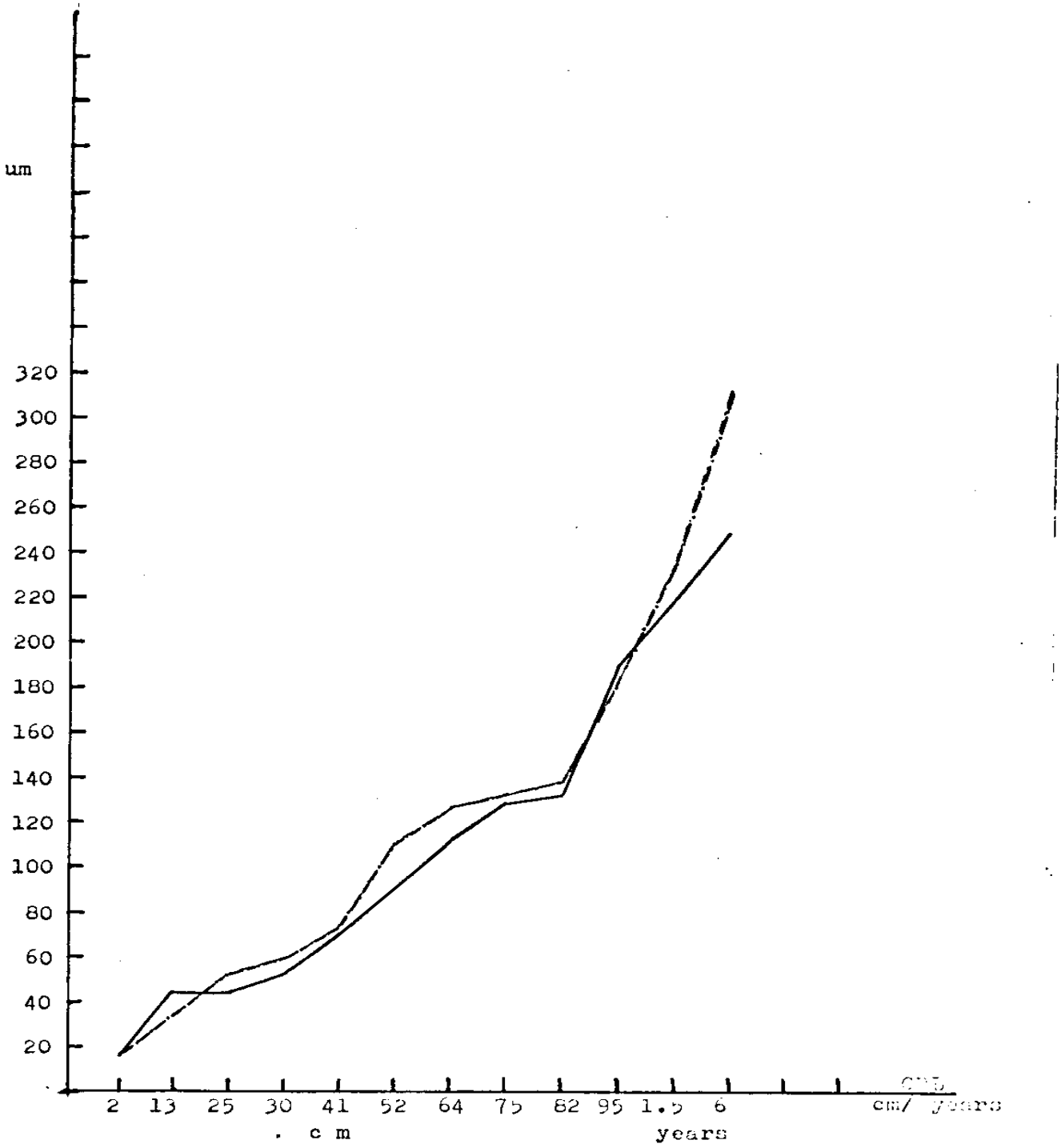


Fig. 26 Lamina epithelialis

——— middle cervical part

-.- thoracic inlet

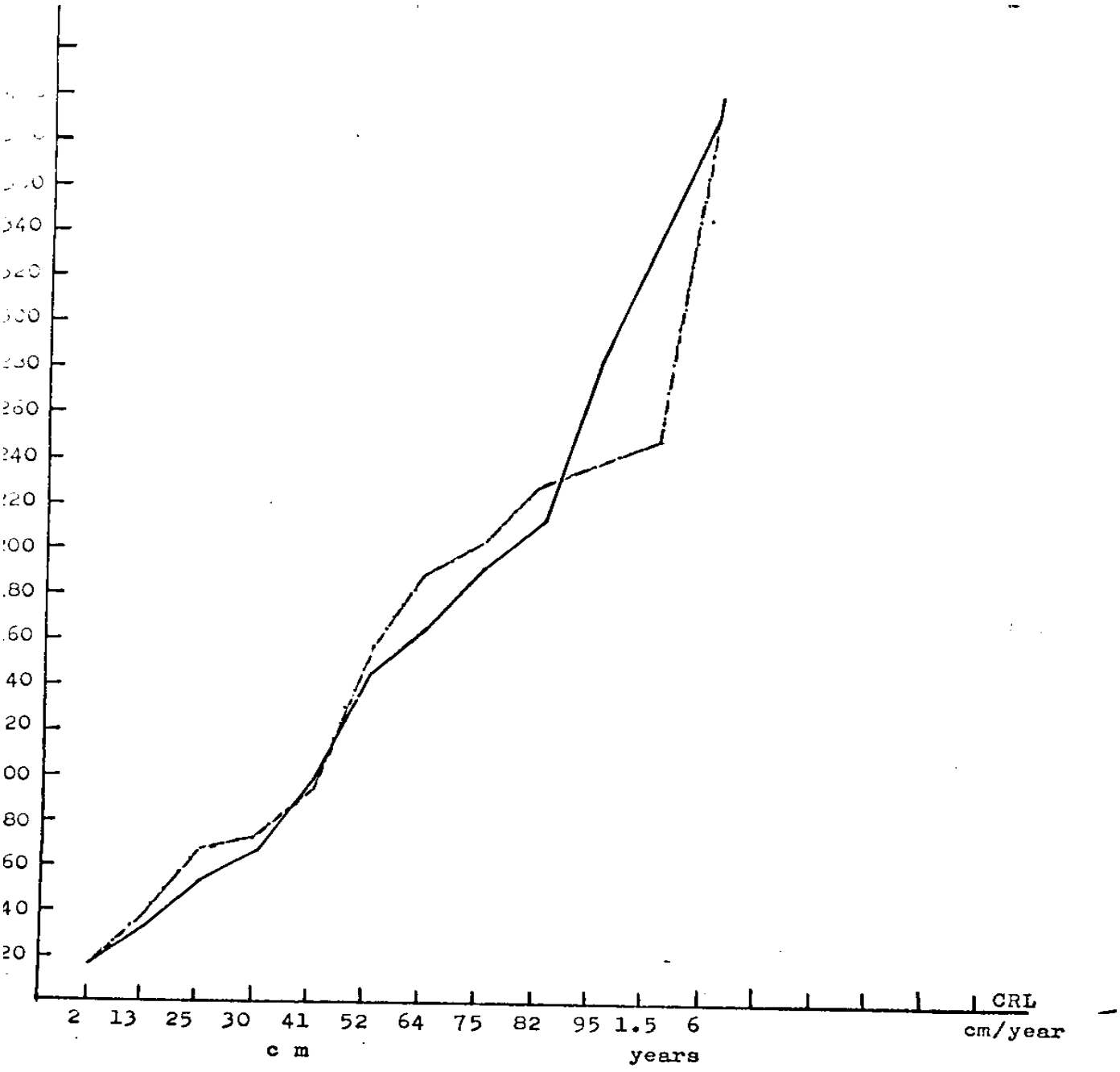


Fig. 27 Lamina epithelialis

-.- at the base of the heart

—— infront of the esophageal hiatus

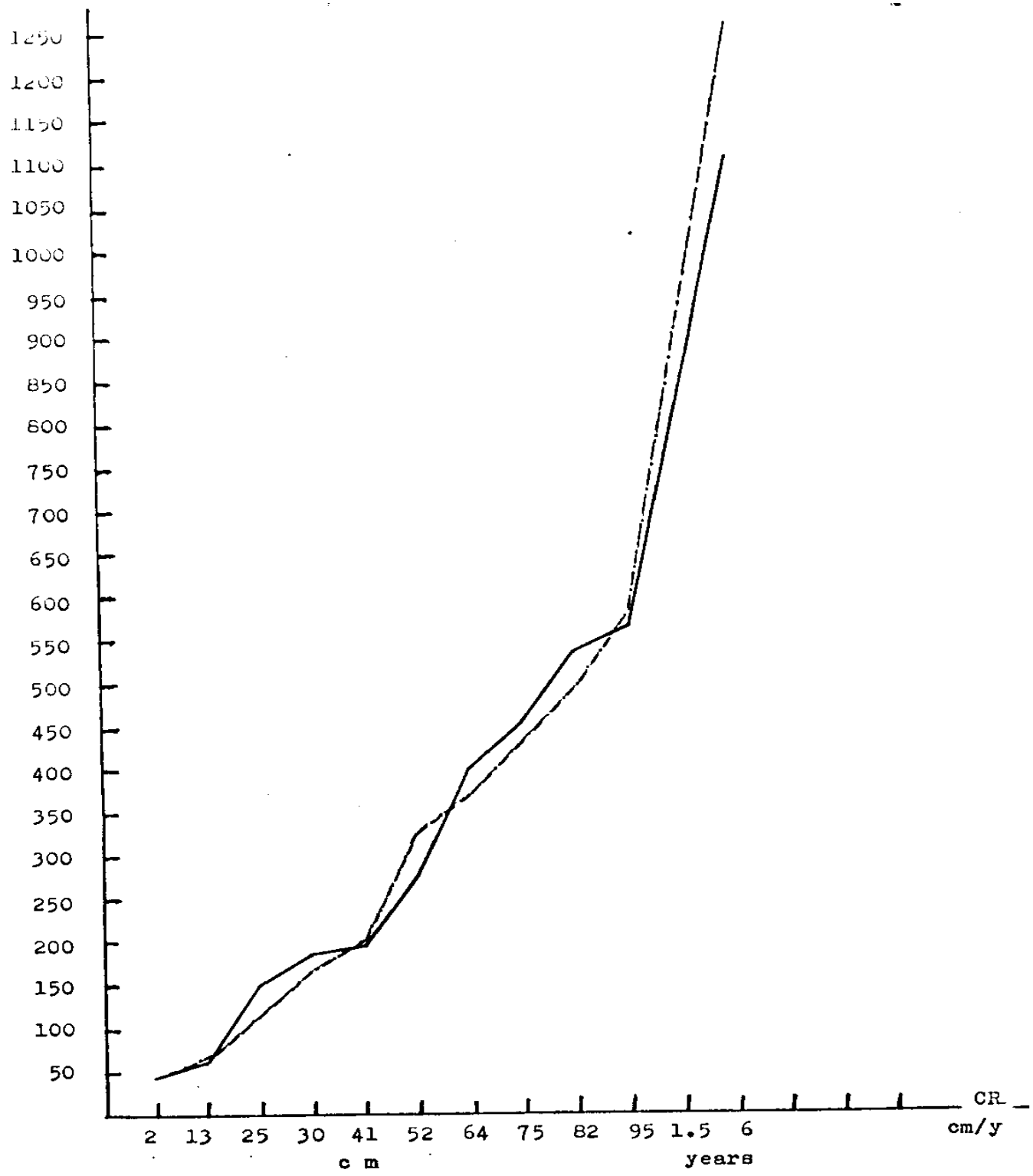


Fig. 28 Lamina propria mucosae/submucosa

—— pharyngo-esophageal junction

-.- middle cervical part

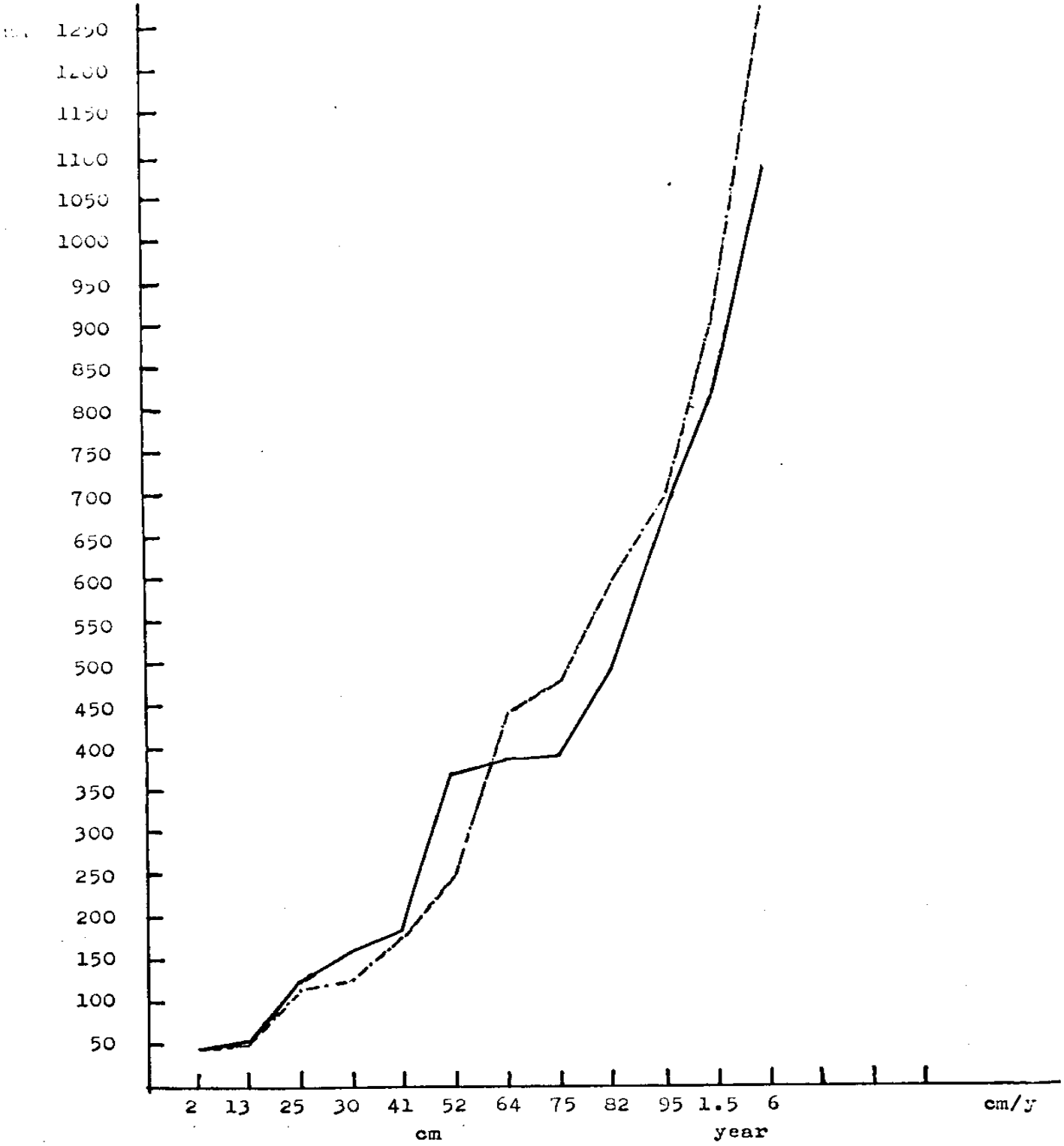


Fig. 29 Lamina propria mucosae/submucosa

—— thoracic inlet

-.- at the base of the heart

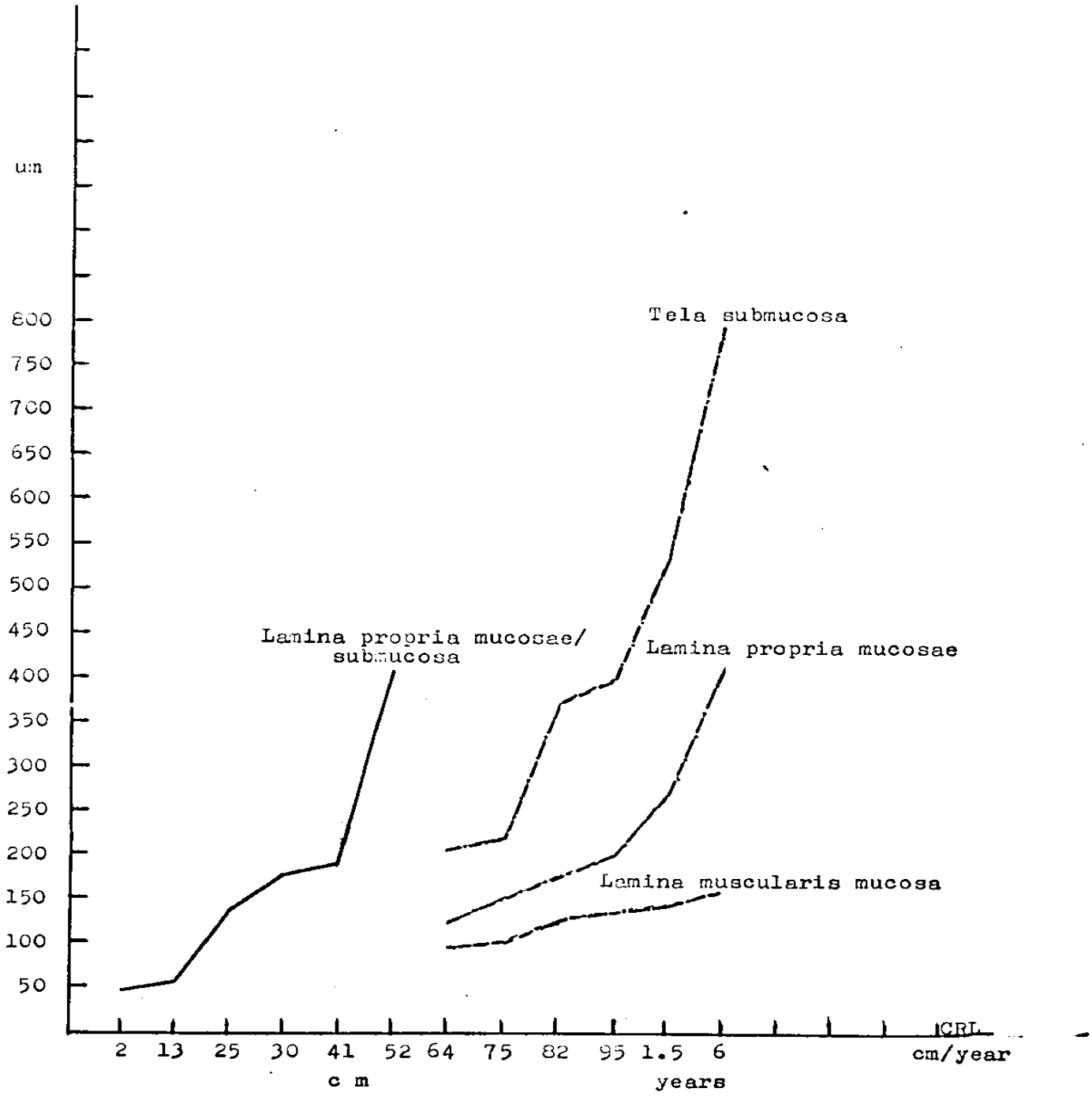


Fig. 30 Lamina propria mucosae/submucosa, in fetuses till CRL 52 cm and Lamina propria mucosae, Lamina muscularis mucosa, Tela submucosa from CRL 64 cm till the adult camel.

Level: Directly infront of the esophageal hiatus.

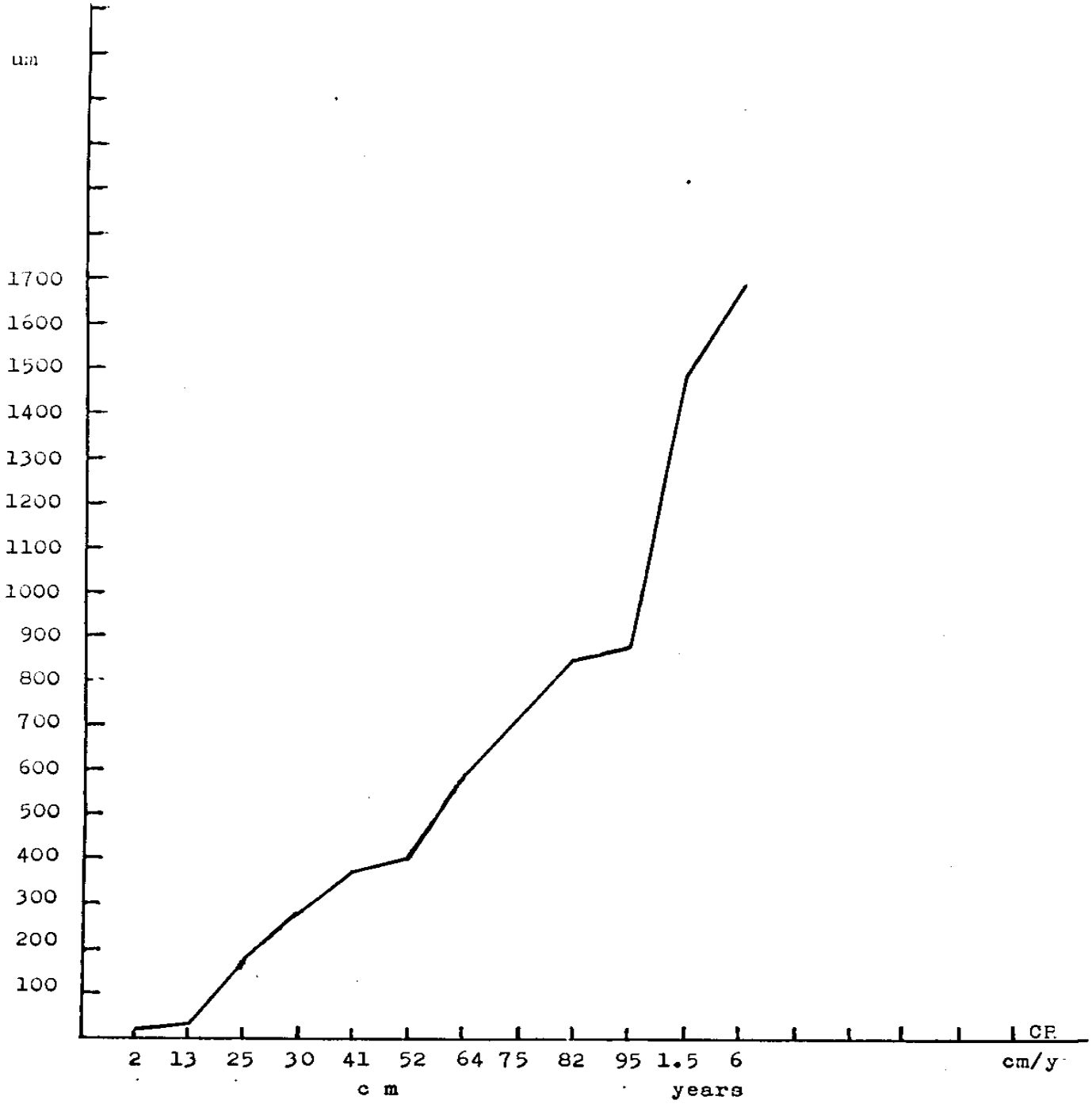


Fig. 31 Tunica muscularis

pharyngo-esophageal junction

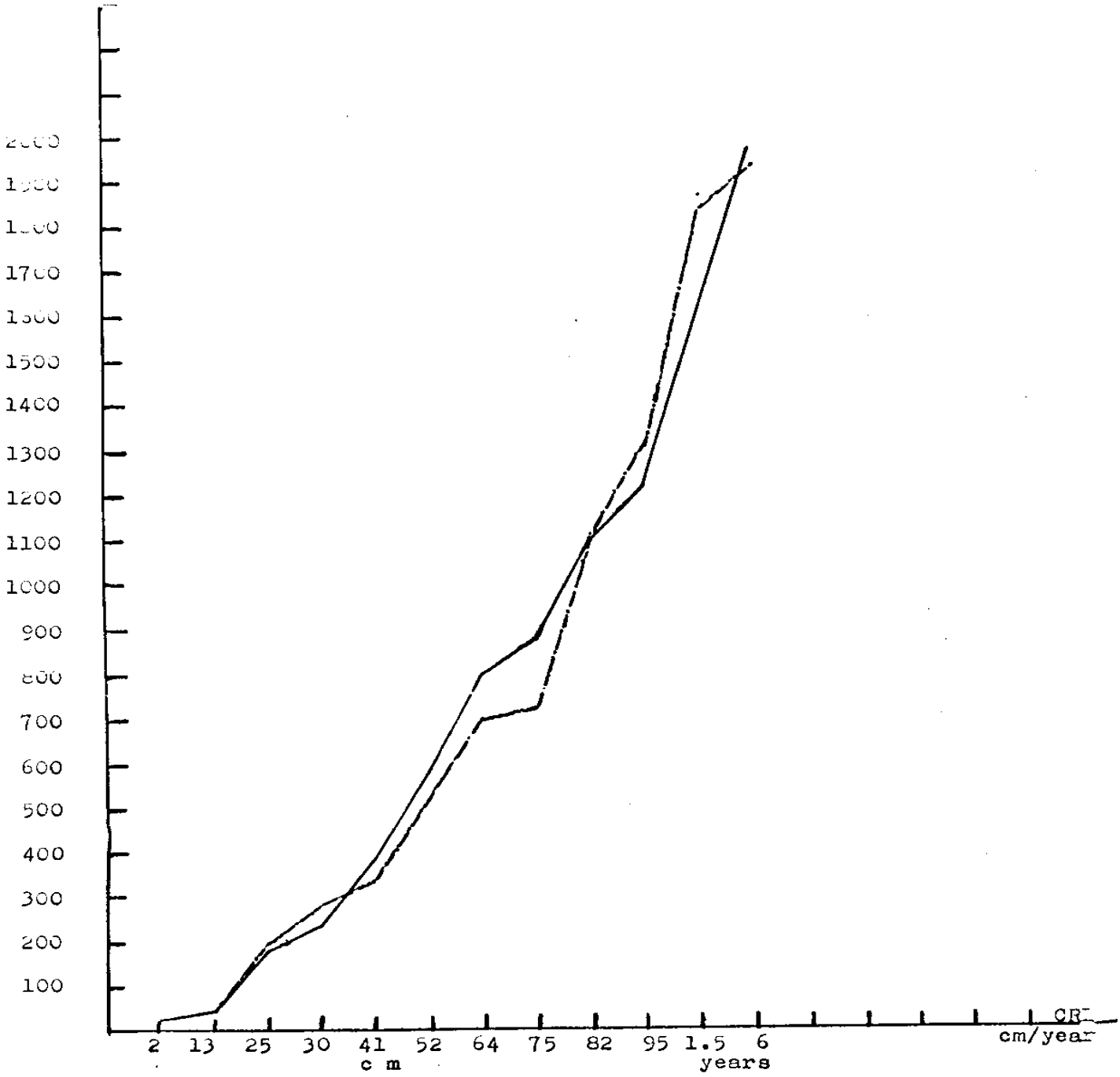


Fig. 33 Tunica muscularis

—— at the base of the heart

-.- cranial of the esophageal hiatus

5.2 Histological studies on the esophagus of the individual camel fetuses, young camel and adult camel

Camel fetus of CVRL 2 cm:

Lamina epithelialis:
It consists of two layers of nuclei, which are spherical in shape and basophilic stained. The cell walls are indistinct; the basement membrane is visible.

Lamina propria mucosae/submucosa:
It is composed of large, undifferentiated mesenchymal cells. Blood vessels are not found.

Tunica muscularis:

It consists of undifferentiated mesenchymal cells, which are fusiform in shape and contain large, oval, basophilic nuclei.

Tunica adventitia:

It is not yet developed.

Camel fetus of CVRL 13 cm (fig. 14):

Lamina epithelialis:

The epithelium is stratified squamous and consists of a superficial and a deep layer. The superficial one comprises 4 - 5 layers of cells, polyhedral in shape, with large, spherical basophilic and centrally located nuclei, containing one or more nucleoli. The cytoplasm is faintly stained with H&E. The cell walls are distinct. The deep or basal layer is composed of one row of densely packed cuboidal to columnar cells, containing a large, rounded

to oval, deep basophilic nucleus. This layer rests on a smooth basement membrane.

Lamina propria mucosae/submucosa:

There is no distinct line of demarcation between the Lamina propria mucosae and the submucosa, but the part near to the Lamina epithelialis is more cellular than that toward the Tunica muscularis, which is more fibrous. In the deeper part of this layer blood vessels of small size are found. They are evenly distributed. No esophageal glands are found in any part from the beginning of pharyngo-esophageal junction till the end of the esophagus (cranial of the esophageal hiatus).

Tunica muscularis:

The Tunica muscularis is distinctly developed and divided into two layers, the inner and outer layer. They are made up of spirally arranged smooth muscle cells (sometimes longitudinally arranged and sometimes also circularly arranged).

Tunica adventitia:

In the cervical part it is composed of loose connective

tissue with blood vessels and fibroblasts. In the thoracic part it consists of loose connective tissue, lined by mesothelium.

Camel fetus of CVRL 25 cm (fig. 8, 15, 18):

Lamina epithelialis:

It is stratified squamous in appearance and consists of two layers. The superficial one has about 5 - 7 cell layers, the cells of which are polygonal in shape, containing a large, spherical, basophilic and centrally located nucleus with one or more nucleoli. The cytoplasm is faintly stained with H&E. The wall of the cells is defined. The deep or basal layer is made up of densely packed cuboidal to columnar cells with a large, spherical or oval and deep basophilic stained nucleus. They rest on the smooth basement membrane.

Lamina propria mucosae/submucosa:

Both, Lamina propria mucosae and submucosa form a common layer, due to the absence of the Lamina muscularis mucosae. The collagenic fibers are well developed. They are more numerous towards the Tunica muscularis than towards the basement membrane.

In the Lamina propria mucosae/submucosa epithelial outgrowths from the Lamina epithelialis are found. They appear as buds from undifferentiated cells. The ends of these buds are enlarged, taking a spherical shape. In solid masses the cells are adherent to each other, without any space between them. The nuclei of these cells are large and spherical in shape. These epithelial outgrowths are found in all parts of the esophagus (pharyngo-esophageal junction, cervical and thoracic parts). They are evenly distributed around the esophageal lumen. In the deeper part of this layer many blood vessels of different caliber are present. They are evenly distributed.

Tunica muscularis:

It is distinctly developed and increased in thickness in comparison to the fetus of CRL 13 cm. It consists of two layers. The inner layer is frequently longitudinally

arranged, but in some parts also circularly. The outer layer is vice versa arranged. Often it is circularly arranged, but in some parts also longitudinally. Smooth muscle cells are spirally arranged.

Tunica adventitia/serosa:

It is composed of loose connective tissue, containing many blood vessels and few fusiform fibroblasts. In the thoracic part it is lined by mesothelium.

Camel fetus of CVRL 30 cm (fig. 11, 21):

Lamina epithelialis:

It carries a stratified squamous epithelium and consists of two layers. They are thicker than the Lamina epithelias of the fetus of CVRL 25 cm. The superficial one has

about 6 - 9 layers of cells with polyhedral shaped, large, spherical, basophilic and centrally located nuclei, containing one or more nucleoli. The cytoplasm is faintly stained with H&E. The walls of the cells are distinct. The deep or basal layer is made up of one layer of densely packed cuboidal to columnar cells with large, spherical to oval, deep basophilic nuclei. The basement membrane is still smooth.

Lamina propria mucosae/submucosa:

The Lamina propria mucosae is blended with the submucosa to form the Lamina propria mucosae/submucosa. The layer towards the basement membrane has more cells, but few collagenic fibers, which are fine and delicate. The layer towards the Tunica muscularis contains many collagenic fibers, but few cells. The Lamina propria mucosae/submucosa is thicker in the cervical part then in the thoracic part of the esophagus. In the Lamina propria mucosae/submucosa epithelial masses or sprouts are seen. They project from the deep layer of the Lamina epithelialis into the surrounding mesenchymous tissue. These epithelial outgrowths appear as large, spherical, solid masses. In the deeper part of this layer also these solid masses are connected with the esophageal lumen by the excretory

ducts. The latter ones also appear as solid masses, but some of them begin to be canalized at the pharyngo-esophageal junction. In the deeper part of this layer many blood vessels of different size are found. They are evenly distributed.

Tunica muscularis:

It is well developed and thicker than that of the fetus of CVRL 25 cm. It consists of two layers. The inner layer is made up of predominantly longitudinally arranged smooth muscle cells, except some parts, in which it is circularly arranged. The outer layer is vice versa.

Tunica adventitia:

It is composed of loose connective tissue with few fibroblasts and many blood vessels. In the thoracic part it is covered by mesothelium.

Camel fetus of CVRL 41 cm (fig. 9):

Lamina epithelialis:

It consists of two layers of stratified squamous epithelium, which are thicker in the thoracic part than in the cervical part. The superficial one contains 8 - 13 layers of polygonal cells with a large rounded basophilic and centrally located nucleus, containing one, or more nucleoli.
The cytoplasm is faintly stained with H&E. The cell boundaries are distinct.
The deep or basal layer is composed of one layer of densely packed cuboidal to columnar cells, containing large, spherical to oval deep basophilic nuclei. These cells rest on a smooth basement membrane.

Lamina propria mucosae/submucosa:

The Lamina propria mucosae and submucosa are blended with each other, having no demarcating line between them. They are thicker in the cervical part than in the thoracic one. The collagenic fibers are well developed and of undulated course. They are numerous near the Tunica muscularis and more cellular near to the Lamina epithelialis. The most of the excretory ducts in all parts of the esophagus are canalized, but the most of the secretory units are still in the form of spherical solid masses.

The few number of the secretory units in the pharyngo-esophageal junction appear centrally canalized. These esophageal glands are evenly distributed. Many blood vessels of different caliber are found in the deep part. They are evenly distributed/

Tunica muscularis:

Both the inner and the outer layer are made up of longitudinally running smooth muscle cells in some parts and of circularly arranged one in other parts. The intermusculso connective tissue begins to appear as very delicate collagenic fibers.

Tunica adventitia:

It is composed of loos connective tissue, which is increased in amount in comparison to the adventitia of the fetus of CVRL 30 cm. They contain many blood vessels and few fibroblasts.

Camel fetus of CRL 52 cm (figs. 10, 12, 16):

The cells in the esophageal lumen are degenerated, containing shrunken pyknotic nuclei.

Lamina epithelialis:

It is formed from two layers (stratified squamous epithelium). It is much thicker than the Lamina epithelialis of the fetus with a CRL of 41 cm and thicker in the thoracic part than in the cervical one. The superficial layer contains about 13 - 17 cell layers. The cells are polygonal in shape, containing large, spherical, basophilic and centrally located nuclei with one or more nucleoli. The cytoplasm is faintly stained with H&E. The boundaries of the cells are very distinct. The basal or deep layer is made up of one row of densely packed cuboidal to columnar cells, containing spherical to oval nuclei, which are deeply basophilic stained. This layer rests on the smooth basement membrane.

Lamina propria mucosae/submucosa:

There is no line of demarcation between the Lamina propria mucosae and submucosa. The part near to the Lamina

epithelialis appears more dark, due to many mesenchymous cells. The collagenic fibers are very distinct and concentrated towards the Tunica muscularis. The excretory ducts of the esophageal glands are completely canalized. Also the most secretory acini are canalized centrally. The nuclei of the epithelial cells in the acini are spherical and basophilic stained. The cell boundaries are indistinct. The glands are evenly distributed around the lumen of the esophagus. Many blood vessels are found in the deeper part of this layer.

Tunica muscularis:

It is highly developed and much thicker in the thoracic part than in the cervical one. It is subdivided by intermuscular connective tissue into two layers, an inner and an outer layer, which are spirally arranged. In the intermuscular connective tissue blood vessels and nerve plexuses are found.

Tunica adventitia:

It is composed of very fine, loosely arranged collagenic fibers, containing blood vessels and nerve plexuses. In the thoracic part it is covered by mesothelium.

Camel fetus of CRL 64 cm (figg. 19, 22):

Lamina epithelialis:

The esophagus is lined by a stratified squamous epithelium, which comprises two layers. It is considerably increased in thickness in comparison to the Lamina epithelialis of the fetus of CRL 52 cm. It is also thicker in the thoracic part of the esophagus than in the cervical one. The superficial layer has about 15 - 20 layers of cells, which are polyhedral in shape, containing large, spherical, basophilic and centrally located nuclei with one or more nucleoli. The cytoplasm is faintly stained with H&E. The boundaries of the cells are very distinct. The basal or deep layer comprises cuboidal to columnar cells, with darkly stained nuclei. The basement membrane is still smooth.

Lamina propria mucosae/submucosa:

Except the caudal part of the esophagus (just cranial of the esophageal hiatus) both, the Lamina propria mucosae and the submucosa, form a common layer, due to the absence of the Lamina muscularis mucosae in these parts of the esophagus. But the Lamina muscularis mucosae is

found in the caudal part of the esophagus, cranial of the esophageal hiatus, thus separating the Lamina propria mucosae from the submucosa. They are composed of longitudinally arranged smooth muscle cells.
All the secretory units and excretory ducts of the esophageal glands are canalized. The secretory units are found in the submucosa in the caudal part of the esophagus, but in the rest of the esophagus they are found in the deeper part of the Lamina propria mucosae/submucosa.
Also many blood vessels are found in the deeper part of this layer.

Tunica muscularis:

It is distinctly increased in thickness and consists of two layers, an inner and outer one, which nearly have the same thickness. They contain spirally arranged smooth muscle cells. The intermuscular connective tissue is well developed, containing blood vessels and nerve plexuses.

Tunica adventitia:

It consists of loose connective tissue with many blood vessels and nerve plexuses. In the thoracic part it is

... covered by mesothelial cells.

Camel fetus of CRL 75 cm:

Lamina epithelialis:

It is made up of two layers. The superficial one includes about 16 - 22 layers of polyhedral cells, containing large, spherical and centrally located nuclei with one or more nucleoli. The walls of the cells are distinct. The cytoplasm is faintly stained with H&E. The basal or deep layer contains cuboidal to columnar cells containing large, spherical to oval, deeply basophilic stained nuclei. The basement membrane begins to be undulated.

Lamina propria mucosae/submucosa:

Both, the Lamina propria mucosae and submucosa, form one layer, except the caudal part, just cranial of the esophageal hiatus. They are separated by the Lamina muscularis mucosae into a Lamina propria mucosae and submucosa. It is composed of longitudinally arranged smooth muscle cells. The collagenic fibers are very extensive and irregular in their course. The secretory units of the

esophageal glands are collected to groups, which show a mucous appearance. Their lumen is moderately wide and the spherical epithelial cell nuclei are pushed to the periphery. The excretory ducts are lined by a layer of cuboidal cells, which change into stratified squamous ones at the terminal part of the ducts.

Many blood vessels and nerve plexuses are found, also in the deep part of this layer.

Tunica muscularis:

The tunica muscularis shows a considerable increase in thickness, especially in the thoracic part and is distinctly separated into two layers. The inner layer is usually longitudinal one, while the outer the is circular But they change more often in the entire course. The intermuscular connective tissue is well developed, containing blood vessels and nerve plexuses.

Tunica adventitia:

It is composed of loose connective tissue with many blood vessels and nerve plexuses. in the thoracic part it is covered by mesothelium.

Camel fetus of CRL 82 cm (fig. 13):

Lamina epithelialis:

The stratified squamous epithelium in comparison to the former stages, is more compressed and solidified. The superficial layer measures about 18 - 23 cells in thickness, containing polyhedral cells with large, spherical basophilic and centrally located nuclei, with one or more nucleoli. The cell boundaries are very distinct. The cytoplasm is slightly eosinophilic, stained with H&E. The basal cell layer is more columnar in shape and the cells have large, oval and deep basophilic nuclei. The basement membrane is undulated, indicating for the first time the advent of the epithelial peg-formation.

Lamina propria mucosae/submucosa:

It is made up of loose, irregular connective tissue, which is more cellular near to the Lamina epithelialis and more vascular towards the Tunica muscularis. The Lamina muscularis mucosae is found only in the caudal part of the esophagus (just cranial of esophageal hiatus). It is composed of longitudinally running smooth muscle cells. In the deeper part of this layer or in the submucosa aggregations

of the esophageal glands are found, which show mucous appearance. The lumen of the glandular end-pieces is moderately wide, and the epithelial cell nuclei are flattened and pushed to the periphery. The excretory ducts are lined by a layer of cuboidal cells, which change into a stratified one at the terminal part of the duct.

Tunica muscularis:

The Tunica muscularis has considerably increased in thickness and is clearly subdivided into two layers, the inner and outer one. They are spirally arranged (sometimes longitudinally and sometimes circularly). Intermuscular connective tissue is well developed. It is rich in blood vessels and nerve plexuses.

Tunica adventitia:

It is well developed and made up of loose connective tissue which is rich in blood vessels and nerve plexuses. In the thoracic part it is covered by mesothelium.

Camel fetus of CRL 95 cm (fig. 20):

Lamina epithelialis:

It consists of two layers (stratified squamous epithelium). Thess are increased in thickness in comparison to the previous fetus of CRL 82 cm and also thicker in the thoracic part than the cervical one. The superficial one is about 15 - 25 cell layers in thickness. The upper four cell layers are flattened, containing flattened nuclei and a deeply stained eosinophilic cytoplasm. The deep layer is composed of one row of densely packed cells with large, spherical and deeply basophilic stained nuclei. This layer rests on an undulated basement membrane, which indicates the beginning of the epithelial peg formation.

Lamina propria mucosae/submucosa:

It is structured like in the previous fetus, but increased in thickness. Except in the caudal part of the esophagus, the Lamina propria mucosae and submucosa form one common layer, due to the absence of a Lamina muscularis mucosae in this part. But in the caudal part (just cranial of esophageal hiatus) they are separated from each other

by the Lamina muscularis mucosae, which is formed by longitudinally running smooth muscle cells. The Lamina propria/submucosa is composed of loose connective tissue, containing blood vessels, nerve plexuses and esophageal glands, which are mucous in nature. The lumen is wide and the nuclei are flattened and pushed toward the base of the cell. The excretory ducts are lined by a single layer of cuboidal cells, changing into stratified ones at the terminal part.

Tunica muscularis:

It is much increased in thickness and subdivided into two layers by a well developed intermuscular connective tissue. The inner layer is predominantly longitudinally arranged and composed of both, smooth muscle cells and striated muscle fibers, while the outer one is predominantly circularly arranged, also consisting of both, smooth muscle cells and striated muscle fibers. Blood vessels and nerve plexuses are found in the intermuscular connective tissue.

Tunica adventitia/serosa:

It is composed of loose connective tissue with many blood vessels and nerve plexuses. In the thoracic part it is

covered by mesothelial cells.

Young camel, 1.5 years of age (fig. 23):

Lamina epithelialis:

The Lamina epithelialis of the young camel is characterized by the presence of a Stratum corneum. Thus, keratinization occurs after birth. It has nearly the same thickness in all parts of the esophagus and is made up of 4 - 5 cell layers. For the first time epithelial pegs are developed. The cytoplasm is more eosinophilic and the nuclei are more basophilic stained with H&E. The cell walls are distinct. The basal cells are columnar in shape with oval and deeply basophilic stained nuclei.

Lamina propria mucosae/submucosa:

It has considerably increased in thickness, except at the caudal part of the esophagus (cranial of the esophageal hiatus). Both form one common layer of dense, irregular connective tissue, which is highly vascular in its deeper part. The excretory ducts of the esophageal glands are in the upper part. At the caudal part of the esophagus the

Lamina propria mucosae and submucosa are separated from each other by very thin smooth muscle bundles of the Lamina muscularis mucosae. The esophageal glands are found in all parts of the esophagus. They form a thick layer of mucous secreting units. The acini are formed of pyramidal cells with distinct boundaries and flattened nuclei at the cell bases. The acinar duct is lined with cuboidal cells, which increase in thickness to a stratified squamous epithelium at the terminal part of the duct.

Tunica muscularis:

It consists of two layers, which are considerably increased in thickness in comparison to the fetal period. The outer and inner layers are made up of striated muscle fibers, which cross each other. The intermuscular connective tissue is well developed and contains blood vessels and nerve plexuses.

Tunica adventitia/serosa:

It is composed of an areolar connective tissue, containing many blood vessels and nerves. In the thoracic part it is covered by mesothelial cells.

Adult camel, 6 years of age (fig. 17):

It carries a keratinized stratified squamous epithelium, which shows an increased thickness in comparison to the young camel, 1.5 years of age. The superficial layer has about 20 - 27 cell layers. The Stratum corneum is considerably increased in thickness, since the stage of the young camel. The epithelial pegs are very distinct. The cells of the superficial layers are flattened with a more eosinophilic cytoplasm and deep basophilic, flattened nuclei. The cells of the Stratum spinosum are polyhedral in shape, containing large, spherical and basophilic nuclei. The basal layer is composed of a single layer of columnar cells with oval, deep basophilic nuclei.

Lamina propria mucosae/submucosa:

Except the caudal part of the esophagus (cranial from the esophageal hiatus) the both form one layer, due to the absence of the Lamina muscularis mucosae. But in the caudal part, they are separated by very fine smooth muscle cells, which are often interrupted by esophageal glands, which form a very thick layer of mucous acini, occupying in some parts the entire submucosa. The excretory ducts have a considerable wide lumen and are lined by a

simple columnar epithelium, which changes into a stratified squamous one at the terminal part of the ducts. Corresponding to the epithelial peg-formation, also the Lamina propria mucosae/submucosa shows a Papillae-occultae-formation.

Tunica muscularis:

It is considerably increased in thickness in comparison to the young camel (1.5 years of age). It consists of an inner longitudinal and an outer circular muscle layer, but it is not uncommon to observe the reverse orientation of the muscle fibers. Few obliquely cut bundles in the same section at different sites are observable. Hence the two muscle layers of the Tunica muscularis appear to be spirally arranged. The intermuscular connective tissue is well developed and contains vessels and nerve plexuses.

Tunica adventitia/serosa:

It resembles to that of the young camel. No differences could be found, except an increase in thickness.

6. Discussion

The present study gives us a comprehensive survey and also some new ideas on the morphology of the esophagus in the camel.

Firstly, we are able to add new findings of the quantitative and qualitative changes in the esophagus of the camel to the quantitative results, gained by BERG, TAHER and MOUSTAFA (1969),

Embryologically and gross anatomically, it can be confirmed that also the growth of the esophagus follows the known principles of development. With increasing age, the esophagus increases in length (12 cm in the CVRL 22 cm-fetus to 127 cm in the young camel and 175 cm in the adult camel. This is of importance for the applied anatomy, because we can conclude from this the length of a probang to be applied by the practicioners or clinicians for the treatment of gastro-intestinal disorders in young and adult camel.

There is lack of Comparable measurements in the available literature, but individual data were given by LESBRE (1903). He described the absolute length of the esophagus of the two - humped camel (Camelus bactrianus)

as to be 2 m, while the present result was (175 cm).
In comparison to the buffalo, one can observe the esophagus of the camel as nearly equal two times the esophagus of the buffalo. The length of the esophagus in the Egyptian water buffalo equals 96cm (ENANY, 1980), in the Indian buffalo 98,72 ± 0.92 cm (SENGAR and SINGH, 1970) and in ox 90 - 105 cm (HABEL, 1975) .
The present result revealed the relation between the cervical part to the thoracic part in all developmental stages, also after parturition. It nearly takes the ratio as 2 : 1. Of no less importance is the diameter of the esophagus (obstruction of the esophagus). Basing on our applied method of measuring, the pharyngo-esophageal junction proved to be the widest part of the esophagus during intrauterine and postnatal development (1.2 mm in the CVRL 22 cm stage to 28.34 mm in the adult camel). After this, the esophagus narrows in diameter. In the cervical part it measures about 22.6 mm (unextended) in the middle cervical part of the adult camel, 20.7 mm at the thoracic inlet, 20.38 mm at the base of the heart and 21 mm in front of the esophageal hiatus. These data may be beneficial for guessing of the diameter of instruments. being applied in the esophagus by practicioners and

clinicians. If we compare the diameter of the camel's esophagus has nearly the same diameter (25 - 30 mm) results in Egyptian water buffalo (ENANY, 1980). Regarding the position of the esophagus, there are practically no changes during the early and late prenatal phases, as also not in the early and late postnatal period. In all developmental stages, the initial part of the espphagus in found over the larynx. It is contineus in this course up to the level of the 5rd cervical vertebra, where the esophagus is found dorso-lateral to the trachea. After this and at the level of the thoracic inlet, we found it completely shifted to the left of the median plane and the trachea. The theracic part passes dorsally in the cranial, middle and caudal mediastinal spaces, forming at the base of the heart the third curvature of the esophagus, which is dorsally convex. Then it curves ventrally and caudally to reach the Hiatus esophageus at the level of 10th thoracic vertebra. In regard to the description of OMAR (1980), that the esophagus gradually shifts to the left of the trachea at the level of 3rd cervical vertebra, the present studies show that the esophagus is dorso-laterally of the trachea, and not on the left side. The following details may explain

the situation. The esophagus is found dorso-laterally to the trachea and due to the neck of the camel it is compressed from side to side. at the same time the trachea begins to deviate to the right side of the median plane. We agree with OMAR(1980) that the esophagus is completely on the left side of the trachea at the thoracic inlet. According to HEGAZI (1945), the esophagus becomes completely on the left side of the trachea at the junction of the upper third with the lower two thirds of the neck. In our studies the esophagus was found completely on the left side of the trachea at the thoracic inlet. The esophagus in the cranial third of the neck is related dorsally to the retro-pharyngeal space and the longus colli muscle, laterally to the carotic vagina and the thymus. In the middle third of the neck it is related dorsally to the retro-pharyngeal space and longus colli muscle, laterally to the carotic vagina and thymus, ventro-laterally to the trachea. At the thoracic inlet the esophagus is dorsally related to the left longus colli muscle, medially to the trachea, laterally to the left carotid vagina and ventrally to the thymus.

The course and the relations of the esophagus in the thoracic part resemble those of the other ruminants (WILKENS and ROSENBERGER, 1957; RAGHAVAN, 1964; KOCH, 1970; DYCE and WENSING, 1971; BERG, 1973, 1974; HABEL, 1975; ENANY, 1980; FUKAYA, et al., 1979).

The abdominal part of the esophagus as absent in the camel fetus and adult camel. similar results recorded the late prenatal and postnatal periods of the bovine esophagus (MULLER-BOTHA, 1962; HABEL, 1975; ENANY,1980).

In the present study we revealed that the esophagus of the camel has three curvatures. The first one is the oephalo-cervical curvature, which is slightly dorsally convex. The second one is the cervico-thoracic curvature, which extends from the 6th cervical vertebra to the 2nd thoracic vertebra. It is concave dorsally. The third one is at the base of the heart (thrracic curvature) and is dorsally convex. Compared with other ruminants we can state, that there are similar curvatures (ENANY, 1980, NICKEL, ScHUMMER and SEIFERLE, 1973).

The retro-pharyngeal space is also present in all investigated

stages of the camel fetuses and extends from the pharyngo-esophageal junction as a wide space, which decreases towards the dorsal mediastinal space. It is filled by loose connective and fat tissue. The same result was recorded in the Egyptian water buffalo by ENANY (1980). Our histological studies have proven the esophagus of the camel as to be a typical tubular organ, composed of the Tunica mucosa with a Lamina epithelialis and a Lamina propria mucosae/submucosa, Tunica muscularis and Tunica adventitia/serosa. The absence of the Lamina muscularis mucosae and the presence of esophageal glands in the whole length of the esophagus has to be considered as a characteristic feature of the camel's esophagus. The Lamina epithelialis is developed from a single layer of epithelial cells. This we could observe at the CRL 2 cm-stage. The same result in the esophagus of the Egyptian water buffalo at the CRL 9 cm-stage described ENANY (1980). SENGAR and SINGH (1969) and MICHEL (1977) reported similar results on the esophagus of the Indian buffalo, resp. the ox.

MICHEL (1977) reported that the epithelium of the esophagus of ox increases so much, that the lumen may be obstructed. This can be also confirmed by our studies. We have seen, that the lumen is at least partially occluded by epithelial

masses in the camel fetuses of 2 cm, 13 cm, 25 cm and 30 cm CRL. WILLIAM, WENDELL-SMITH and TREADGORD (1976) described the same phenomenon in man. There, with the descent of the heart and diagphragm, the foregut becomes elongated rapidly to form the esophagus. The elongation is accompanied by a temporary obliteration of its lumen, followed by a recanalization and differentiation of the stratified squamous epithelium. From our studies we revealed, that the epithelium increased with increasing crown rump length. At CRL of 13 cm, the Lamina epithelialis is composed of a stratified squamous epithelium, having two layers. The superficial one has about 4 - 5 layers of cells, polyhedral in shape, with large and spherical basophilic and centrally located nuclei. The basal layer is composed of one row of densely packed cuboidal to columnar cells, containing a large, rounded to oval, deep basophilic nucleus. The Lamina epithelialis continuously increases in thickness and the number of cell layers. At CRL of 82 cm, about 18 - 23 cell layers in thickness are found, from which the upper two or three ones are flattened. The cells contain flattened nuclei and more or less eosinophilic cytoplasm. The keratinization appears postnatally in the young camel. The Stratum corneum is very clear and increases in thickness with age. The same

result was found in the Egyptian water buffalo by ENANY (1980). The quantitative histological studies revealed a continuous increase in the esophageal wall. That of the thoracic part is much thicker than that of the cervical one. The thinnest wall has the cervical part of the esophagus and this is to be discussed in close association to the surrounding of the esophagus by many cervical muscles (striated musculature), which act on the esophageal wall and on its content, relieving in this manner the activity of the Tunica muscularis. The result is the relative weak development of the Tunica muscularis. The again increased wall of the thoracic part of the esophagus may have its reason in the lack of such a surrounding of musculature. The Tunica muscularis of the esophagus depends on itself and is consequently thicker than in cervical part.

In all portions of the esophagus (pharyngo-esophageal junction, cervical part and thoracic part) the Lamina epithelialis increases absolutely. The pharyngo-esophageal junction has a thickness of the Lamina epithelialis of 27.12 µm at the CRL of 13 cm and of 230.52 µm in the adult camel. In the middle cervical part it measures 42.94 µm at CRL 13 cm and increases to 248.6 µm in the adult camel. At the thoracic inlet the corresponding

values are 37.29 µm at the CRL of 13 cm and 316.96 µm in the adult camel. At the base of the heart the values are 39.35 µm at the CRL 13 cm-stage and 400.02 um in the adult camel. Directly cranial from the Hiatus esophagus the Lamina epithelialis measures 36.16 µm at the stage of CRL 13 cm and 389.09 µm in the adult camel.

In our studies we observed that the Lamina propria mucosae and the submucosa form one layer (Lamina propria mucosae/submucosa) at the beginning (CRL 2 cm). This layer is composed of large, undifferentiated mesenchymal cells. With increasing crown-rump-length they are differentiating into collagenic fibers and fibroblast cells. In the early stages of the development, the Lamina propria mucosae/submucosa is composed mainly from collagenic fibers. The elastic fibers begin to appear at a CRL of 82 cm as very fine and delicate fibers in the deeper part of this layer and around the esophageal glands. Also this layer contains a large amount of blood vessels of different calibers.

It could be observed that the Lamina muscularis mucosae is absent from the whole length of the camel fetuses up to a CRL of 64 cm, where at this age the Lamina muscularis mucosae begins to develop at the caudal part of the esophagus, just infront to the esophageal hiatus, as

very delicate smooth muscle cells, which are longitudinally arranged. The Lamina muscularis mucosae remains restricted only to this part of the esophagus. Even in the adult camel it does not extend cranially at all. In comparison to this ENANY (1980) observed in the Egyptian water buffalo that the Lamina muscularis mucosae in the whole esophagus occurs except the pharyngo-esophageal junction.

RAMKRISHNA and TIWARI (1978) observed that the Lamina muscularis mucosae separates the Lamina propria mucosae from the submucosa for the first time at the caudal end, then at the cranial end of the caprine esophagus.

STINSON and CALHOUN (1976) found the Lamina muscularis mucosae as absent in the cranial end of the esophagus of pig and dog, but present in the whole length of the esophagus of horse and ruminants. The present study revealed the Tunica muscularis as consisting mostly of an inner longitudinal and an outer circular muscle layer. But it was not uncommon to observe also a longitudinal and circular orientation of the muscle fibers. Hence, the two muscle layers of the Tunica muscularis appeared to be arranged spirally.

We agree with LESBRE (1903) in describing the Tunica muscularis as to be formed by circularly running fibers

et its surface, by longitudinally or more or less spirally running ones in the depth. Also we agree with RAMKRISHNA and TIWARI (1978), which observed the same arrangement of the Tunica muscularis in the esophagus of the goat. Also, Moreover agree with CHRISTOPH (1980), who described the Tunica muscularis of the esophagus in dog as not consisting of an outer longitudinal and an inner circular layer. But the two layers of skeletal musculature form polar screw-like fascicles, that run in the opposite direction, if compared with the Tunica muscularis of the bovine esophagus (ENANY, 1980).

TIWARI (1978) described the Tunica muscularis as consisting of spirally or obliquely arranged striated muscle fibers. The two layers are arranged longitudinally, obliquely or circularly and change their direction.

the present research revealed that at CVRL of 25 cm the esophageal glands in the whole length of the esophagus, from the pharyngo-esophageal junction up to the cardiac opening of the stomach, It appears for the first time as solid epithelial masses in the Lamina propria mucosae-submucosa and are connected with the Lamina epithelialis by a strip of solid epithelium, representing the excretory duct. The canalization appeared for the first time in the excretory duct at a CVRL of 30 cm and in the secretory

unit at a CRL of 41 cm. After this, the excretory ducts and secretory units are completely canalized at a CRL of 64 cm. The lumen of the secretory end-pieces increase in diameter. The nucleus of the secretory cells becomes pushed towards their base. The boundaries of the cell are very clear, taking the characteristic feature of mucous glands at a CRL of 82 cm.

In the young and adult camel a lot of mucous glands are found in the Lamina propria mucosae/submucosa, which occupy roughly the half of this layer. These mucous glands keep the esophagus of the camel in a constant moisture as a long transport organ. The camel can eat without drinking for a long time. The presence of these glands make a lubrication of the esophagus to facilitate the passage of the food and also to facilitate probably the resistance against thirst, to which this animal may be subjected to a high degree.

We agree with LESBRE (1903), who observed the same in the two-humped camel.

In comparison to our findings ENANY (1980) and TIWARI (1977) observed the mucous glands only at the pharyngo-esophageal junction of the buffalo esophagus.

STINSON and CALHOUN (1976) described the esophageal glands of ox as mixed glands, containing mucous acini

with serous demilunes. They are also characteristic for pig and dog. In the pig the glands are abundant in the cranial half, but do not extend into the caudal half, meanwhile in the dog they are present throughout, extending into the cardiac region of the stomach. The glands are present only at the pharyngo-esophageal junction in horse, cat and ruminants. Mixed acini and demilunes in cattle were also observed by WAKURI and MUTO (1972).

COPENHAVER et al. (1971) mentioned the glands of the esophagus in human as typical mucous alveoli.

7. Summary

In 19 camel fetuses (Camelus dromedarius) ranging from 20 - 100 cm CRL, one young camel and two adult ones, the esophagus was studied anatomically and in 10 camel fetuses, ranging from 2 - 95 cm CRL, one young camel and one adult camel histologically.

By this, the development of the early and late prenatal in addition to the early and late postnatal stages were covered. The position of the esophagus is unchanged during all the developmental stages. At the pharyngo-esophageal junction, it lies dorsal to the larynx, at the cervical part on the dorso-lateral aspect of the trachea, at the thoracic inlet on the left side of the trachea and at the thoracic part dorsal to the trachea. The length, the diameter and the thickness of the esophageal wall increase with the increasing age. The length of the esophagus in the adult camel is about 175 cm, the diameter about 21 mm in the adult camel. The esophagus of the camel can be divided into a pharyngo-esophageal junction, a cervical and a thoracic part.

An abdominal part is absent.
The cervical part is nearly equal two times the thoracic part in its length, but at the same time, the thoracic part has a thick wall and narrow diameter on the contrast to the cervical part.
The Lamina epithelialis is composed of a stratified squamous epithelium, the number of cells of which increases with age of the fetuses. Keratinization occurs after birth and in connection to this also the interpapillary peg-formation.
A Lamina muscularis mucosae is absent from the whole length of the esophagus of the camel-fetuses up to a CRL of 64 cm. It only appears in the caudal part of the esophagus, just infront of the esophageal hiatus.
The esophageal glands are present in all the parts of the esophagus and equally distributed around the esophageal lumen. First epithelial sprouts project from the Lamina epithelialis into the Lamina propria mucosae/ submucosa (CRL 25 cm). Later on, first the excretory ducts become canalized (CRL 41 cm) and finally the solid glandular epithelial sprouts (CRL 64 cm). The esophageal glands are predominantly of mucous character.
The Tunica muscularis consists of longitudinally and circularly arranged smooth muscle cells in the early

stages of development, which change into striated musculature in the late stage of development. They are spirally arranged.

The Tunica adventitia consists of loose connective tissue at the pharyngo-esophageal junction and in the cervical part. At the thoracic portion it is surrounded by mediastinal pleura.

8. Conclusions

The esophagus at its begening lies over the larynx, in middle third of the neck dersolateral to the trachea and in the caudal third left to the tranchea.
Esophageal glands are present in the whole length of the esophagus.
The Lamina muscularis mucosos is absent from the whole length of the esophagus, except the caudal part, just cranial from the esophageal hiatus.

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ملخص عربـــــى

درس المرىء تشريحيا فى تسعة عشر من أجنه الجمال وحيدة السنام يتراوح اطوالها بين ٢٠ــ١٠٠ سم وجمل غير بالغ وجملين بالغين . كما تمت الدراسة الهستولوجية فى عشر أجنه جمال يتراوح طولها بين ٢٠ــ٩٥ سم وجمل غير بالغ وجمل بالغ .

وقد لوحظ من خلال هذه الدراسات ان الوضع التشريحى للمرىء لايتغير خلال مختلف مراحل النمو . يقع الاتصال البلعومى المرىء على السطح العلوى للحنجرة والثلث العلوى من المرىء العنقى على السطح العلوى للقصبة الهوائية والثلث الاوسط من المرىء العنقى يقع على السطح العلوى الجانبى للقصبة الهوائية من ناحية اليسار والثلث السفلى من المرىء العنقى يقع على الجانب الايسر للقصبة الهوائية بينما يقع الجزء الصدرى من المرىء على السطح العلوى للقصبة الهوائية .

وقد لوحظ أيضا اتجاه بتطور العمر يزداد كل من طول وقطر وسمك جدار المرىء حيث يبلغ طول المرىء فى الجمل البالغ ١٧٥ سم والقطر حوالى ٢١ سم وينقسم المرىء فى الجمل الى الاجزاء التالية :

جزء يمثل الاتصال البلعومى المرىء . جزء عنقى وجزء صدرى بينما الجزء البطنى غير موجود . يعتبر الجزء المنقلى من المرىء أطول جزء ويبلغ طوله ضعف الجزء الصدرى من المرىء تقريبا ولكن فى نفس الوقت يعتبر الجزء الصدرى من المرىء أسمك وأقل فى القطر من الجزء العنقى للمرىء .

تتكون الصفيحة الطلائية لجدار المرىء فى الجمل من خلايا حرشفية عديدة

الطبقات يزداد عددها بزيادة العمر. وقد لوحظ أن عملية التقرن تظهر بعد الولادة. وقد لوحظ أن الصفيحة المضلية المشاطية لم يظهر في مرئ أجنة الجمل حتى طول ٦٤ سم تبدأ بعدها في الظهور في الجزء الاخير من المرئ وبالتحديد الجزء المواجه للحجاب الحاجز ولم تمتد الى الامام.

وقد لوحظ أيضا أن غدد المرئ تظهر لاول مرة في جنين الجمال البالغ ٢٥ سم في الطول وموجودة في جميع أجزاء المرئ من الاتصال البلعومي المرئ حتى اتصال المرئ بالكرش وتكون موزعة توزيعها متساويا حول تجويف المرئ وتبدأ القنوات الاخراجية لغدد المرئ في التجوف في جنين الجمل البالغ طوله ٤١ سم والغدد الافرازية تكون مجوفة تماما في جنين الجمل البالغ طوله ٦٤ سم . هذه الغدد تكون بوجه عام مخاطية الافراز.

وتتكون الطبقة المضلية في بداية العمر من حزم طوالية ودائرية من خلايا عضلية ملساء مرتبة بطريقة حلزونية تتغير الى ألياف عضلية مخططة بتقدم العمر.

يحاط كل من جزء البلعومي المرئ والجزء العنقي من المرئ بطبقة غير كثيفة من الانسجة الضامة أما الجزء الصدري فانه يحاط بالغشاء البلوري.

قـــرار لجنـــة الحـــكم و المناقشـــه

قـــررت لجنـــه الحـــكم و المنـــاقشه التـــوصيه بمنـــح السيـــــد / طـ٠ب / محمـــد السيـد أيمـــن ســـلامه درجـــة المـــاجستير فـــى العـــلوم الطـــبيه البيـــطريه (تخصص تشـــريح الحيـــوان)

اللجـــنـــه

أ ٠ د / محمـد صلاح الـدين محمـد مصطفى — أستـاذ التشريح بكليـه الطب البيطـــرى جامعة القـــاهره

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٦٠٢

جامعة الاسكندرية
كلية الطب البيطرى (بأدفينا)
قسم التشريح والهستولوجيا

دراسات تشريحية ومجهرية على مرىء الجمل فى أطوار النمو

رسالة مقدمة من

ط ٠ ب / محمد السيد أمين سلامة
بكالوريوس العلوم الطبية البيطرية (١٩٧٨)

المحصول على درجة الماجستير فى العلوم الطبية البيطرية
تخصص (تشريح)

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١٩٨١