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THE TOPOGRAPHY AND THE MICROSCOPIC STRUCTURE OF TONSILS IN THE ADULT BACTRIAN CAMEL (*Camelus bactrianus*)

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ABSTRACT

Anatomical localisation and histology of tonsils were studied in 10 adult bactrian camels (*Camelus bactrianus*) aged between 5 to 10 years. Six tonsils were present: the palatine tonsil, the lingual tonsil, the tonsil of the soft palate in the oropharynx, the pharyngeal tonsil, the tubal tonsil in the nasopharynx, and the paraepiglottic tonsil in the laryngopharynx. The palatine, pharyngeal and paraepiglottic tonsils were readily visible macroscopically. They consisted mainly of secondary lymph nodules. Secondary lymphoid nodule was comprised of 4 areas: follicle-associated epithelium (FAE), dome area (DA), follicular area (FA) and parafollicular area (PFA). The tubal tonsil and the tonsil of the soft palate were macroscopically visible after fixation in 2% acetic acid. These tonsils consisted of scattered lymph nodules, aggregations of lymphocytes and diffuse lymphoid tissue. Because of closely adjacent anatomical position, the palatine tonsil and the paraepiglottic tonsil were lined with stratified squamous epithelium. The pharyngeal tonsil and the tubal tonsil were lined with pseudostratified columnar ciliated epithelium. The epithelium covering the tonsils and their crypts was frequently infiltrated heavily by lymphocytes. The palatine tonsil possessed a large number of obvious crypts which increased the epithelial surface area potentially exposed to antigen. The surface of the soft palate were lined with stratified squamous slightly keratinised epithelium. The lingual tonsil could not be located by any macroscopic landmarks, even with fixation in 2% acetic acid.The lingual tonsil was consisted of small aggregations of lymphocytes. The results indicates that 6 tonsils in the adult bactrian camel have the cytologic basis of normal mucosa reaction, which may play a major role in immune responses.

Key words: Bactrian camel, histology, tonsil, topography

The mucosa-associated lymphoid tissue (MALT) initiates immune responses to specific antigens encountered along all mucosal surfaces (Cesta, 2006). Similar to Peyer's patches and the vermiform appendix, the tonsils belong to MALT (Perry and Whyte, 1998). The tonsils (tonsillae or amygdalae) consist of an accumulation of lymphocytes which are usually concentrated in lymph nodules and are present in the mucosae of the oropharynx, nasopharynx and laryngopharynx of most species except rodents (Perry and Whyte, 1998; Cocquyt *et al,* 2005; Cesta, 2006), forming the so-called Waldeyer's ring (Perry and Whyte, 1998). This location involves an important role for tonsils as secondary lymphoid tissue in the immunological response against antigens which enter the body by the oral or nasal route (Cocquyt *et al,* 2005). Tonsils can also form a route of entry and a replication site for some pathogens of which prions causing bovine spongiform encephalopathy (BSE) are of major importance (Jeffrey *et al,* 2001; Hunter, 2003; Bellworthy *et al,* 2005). Tonsils are not only important tissues to diagnose overt diseases, but also to detect clinically inapparent carriers (Liebler-Tenorio and Pabst, 2006).

In contrast to small laboratory rodents, the lymphoid tissues of Waldeyer's ring are well developed in farm animals and humans (Liebler-Tenorio and Pabst, 2006). Six tonsils are described in sheep: the palatine tonsil, the lingual tonsil and the tonsil of the soft palate in the oropharynx, the pharyngeal tonsil and the tubal tonsil in the nasopharynx, and the paraepiglottic tonsil in the laryngopharynx (Cocquyt *et al,* 2005). No paraepiglottic tonsil is present in cattle (Casteleyn *et al,* 2008b). The topography and structure of these tonsils in camel are poorly documented. The paraepiglottic tonsils are readily visible macroscopically and bilaterally present at the base of the epiglottis in the bactrian camel (Yang *et al,* 2010). The objective of the present study was to explore the microscopic structure of the tonsil in the camel

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because of the importance of these organs as sites of attachment and entry of microbial pathogens and vaccines.

Materials and Methods

The heads of 10 adult (5-10 years) healthy bactrian camels of both sexes were obtained from the slaughterhouse of the Right Alasan Banner Food Company in Inner Mongolia Autonomous Region, China, after the animals had been killed by exsanguination for human consumption. Five of these heads were used for the macroscopic examination and the tonsils of the 5 remaining heads were excised for microscopic examination.

The skin and mandibles were removed from all 10 heads and five heads were sectioned in the median plane. The heads were rinsed with tap water for 5 min and fixed in 2% acetic acid for 24 h to visualise the lymph nodules (Cocquyt *et al,* 2005; Cornes, 1965). The location of the lymph nodules was noted, the length and width of the tonsils were measured and the number of lymph nodules was counted. The base of the tongue, the palatine tonsil, the soft palate, the pharyngeal septum, the lateral pharyngeal wall surrounding the pharyngeal opening of the auditory tube and the paraepiglottic tonsil were collected from 5 heads. These samples were fixed in 10% formaldehyde for 24 h, dehydrated, cleared and embedded in paraffin. Embedded tissues were cut into 8 µm thick sections with a 100 µm interval. The slides were stained with hematoxylin and eosin (H&E). Special attention was given to the differentiation of lymph nodules (primary or secondary nodules), the parafollicular tissue, the overlying epithelium and the connective tissue surrounding the lymphoid tissue. Lymph nodules were defined as compact nodular aggregates of lymphocytes surrounded by a diffuse sheet of lymphoid tissue (Thuring *et al,* 2002).

Results

The palatine tonsil

The pair of palatine tonsils were located in the pharynx between the palatoglossal and the palatopharyngeal arch (Fig 1, Fig 2, Fig 3-A), which were consisted of several independent spherical macroscopically visible nodules of the pharyngeal mucosa with one or two narrow elongated entrances to the underlying crypts (Fig 2). The area of the tonsil without the crypts on each side was about 23 cm^2, with 3–5 nodules per cm^2 (Fig 3-B,C). The mucosal surface of each nodule was covered by a keratinised stratified squamous epithelium continuous with that of the buccal mucosa. The squamous epithelium that covered the surface formed tonsillar crypts by invaginating into the underlying connective tissue. The crypts were often branched (Fig 4-A, B) and had a large lumen which was sometimes occluded by mucous or cellular debris (Fig 4-A). Numerous secondary lymph nodules were located in the walls of these crypts. Well-developed germinal centres were observed in all lymphoid nodules. The stratified epithelium of the crypts was frequently infiltrated heavily by lymphocytes (Fig 4-A).

The lingual tonsil

The lingual tonsil could not be located by any macroscopic landmarks. Aggregations of lymphoid cells were located at the dorsal surface of the tongue without reaching the midline and mainly in the area extending from the last papilla vallata to 2 cm rostral to this structure (Fig 2). The lingual epithelium was stratified, squamous and keratinised. Neither any infiltration of lymphocytes in the stratified squamous epithelium of the tongue nor any tonsillar crypts were seen (Fig 5). The lymphoid cells were mainly organised in small dense aggregations or were scattered in the propria–submucosa layer (Fig 5). Two primary nodules were observed only in 3 out of 10 tongues.

The tonsil of the soft palate

No macroscopic signs of this tonsil were observed on the ventral (oral) surface of the soft palate (Fig 1). In contrast, on the dorsal (nasal) side, scattered nodules of lymphoid tissue varying in number from 20 to 150, were made visible by the acetic acid. The surface was lined with stratified squamous slightlykeratinised epithelium with an irregular free surface and internal papillary pegs at the nasopharyngeal side of the soft palate. The stratum basale layer contained round to oval irregular nuclei (Fig 6-A). Loose irregular connective tissue, lymphoid and glandular tissues comprised the lamina propria mucosae. Subepithelial lamina propria mucosae were absent in areas where the epithelium was associated with lymphoid tissue. Primary and secondary lymph nodules which were covered by a thin, slightly keratinised squamous epithelium could be observed in the middle part and distributed irregularly and separated by fine collagen fibres. The epithelium of the nasal side of the soft palate was sometimes infiltrated by lymphocytes in the area above the lymph nodules and aggregated lymphocytes (Fig 6-A). High endothelial venules (HEVs) separated by a meshwork

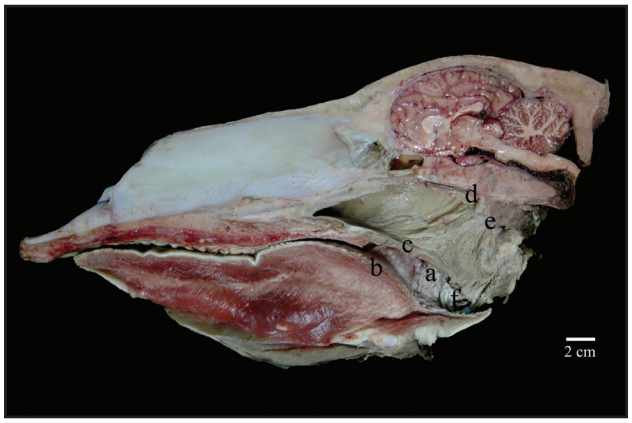

Fig 1. Median section of a camel head, (a) palatine tonsil; (b) lingual tonsil; (c) tonsil of the soft palate; (d) pharyngeal tonsil; (e) tubal tonsil; (f) paraepiglottic tonsil.

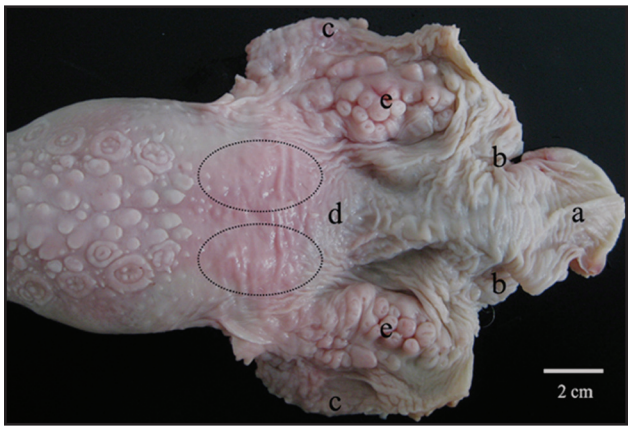

Fig 2. Dorsal view of the larynx and tongue of the camel. Ellipse: location of the lingual tonsil; (a) epiglottis; (b) paraepiglottic tonsil; (c) soft palate (sectioned); (d) root of tongue; (e) palatine tonsil.

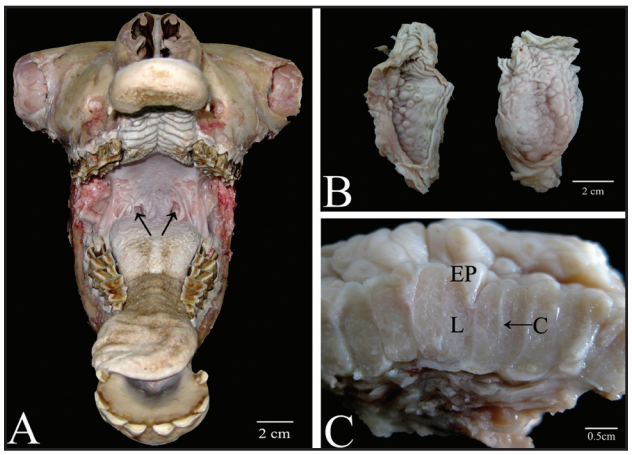

Fig 3. A: Widely opened jaws of a camel showing the location of the palatine tonsils (arrows) in the oropharynx. B: Mucosal surface of a palatine tonsil showing crypt entrances. C: Macrograph of cut surface of the palatine tonsil showing crypt (C, arrow), lymphoid tissue (L) and the epithelium (EP).

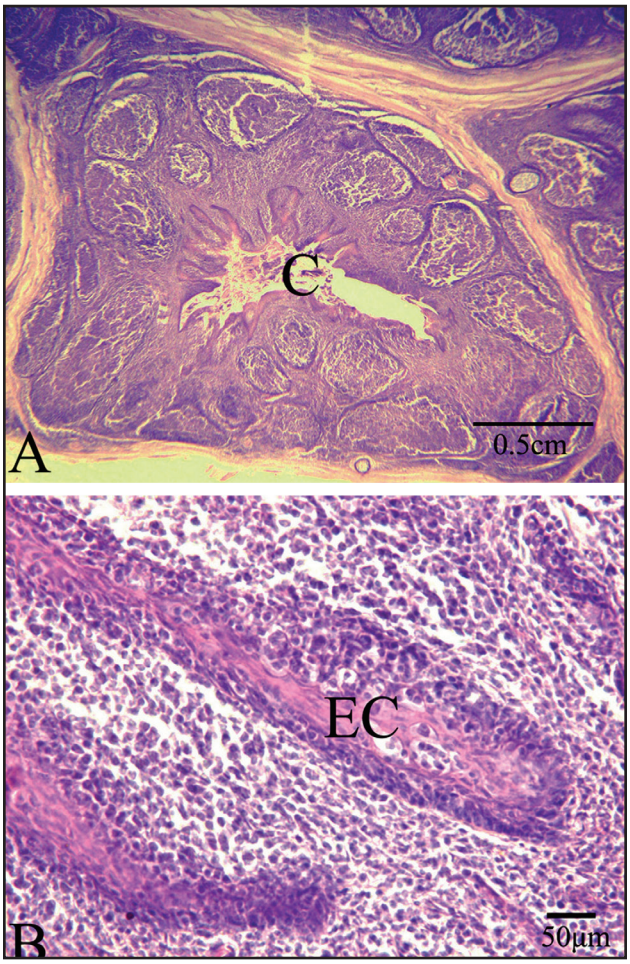

Fig 4. A: Histological section of the palatine tonsil showing an aggregation of lymph nodules with a central crypt (C); B: The epithelium of the crypt (EC) is infiltrated by numerous lymphocytes. (H&E).

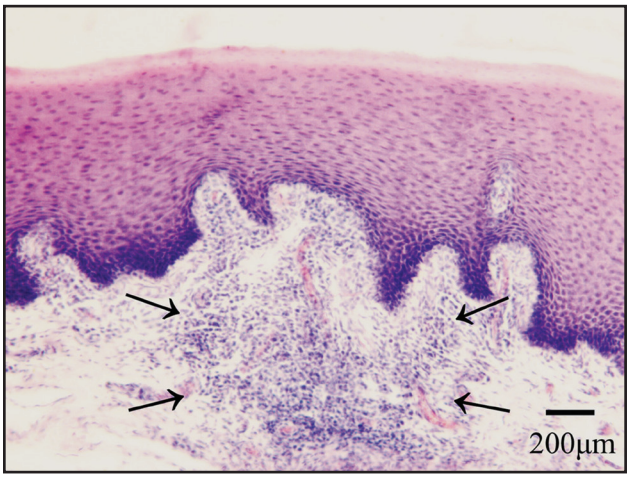

Fig 5. Histological section of the lingual tonsil showing aggregation of lymphocytes (arrows) in the subepithelial connective tissue (H&E).

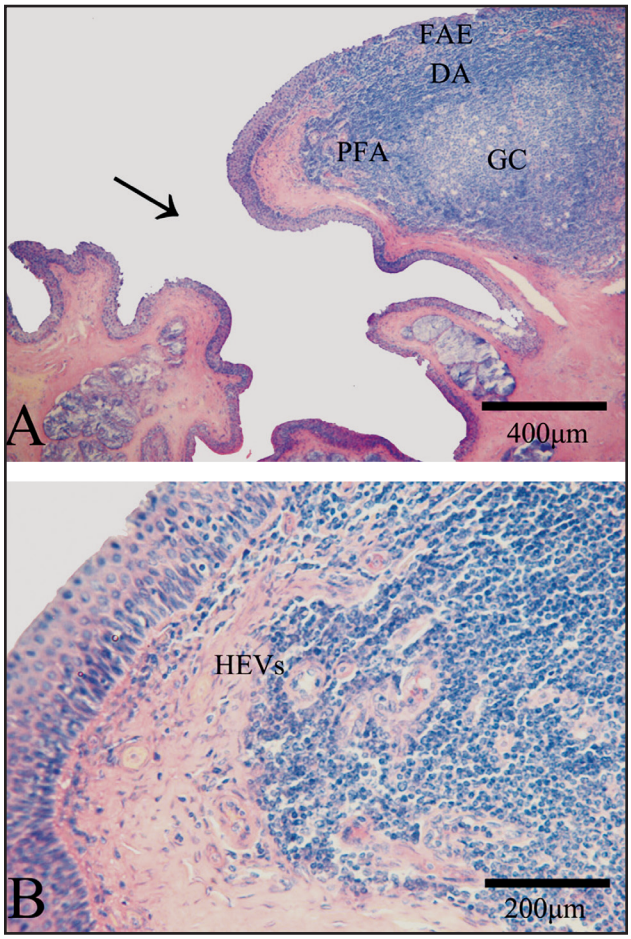

Fig 6. Histological section of the tonsil of the soft palate showing nodules in the dorsal (nasal) part of the soft palate with lymphocyte infiltration in the epithelium above the nodules. Note: the epithelial holes (arrows); dome area (DA); follicle-associated epithelium (FAE) and germinal centers (GC). B: Histological section of the tonsil of the soft palate showing high endothelial venules (HEVs) in parafollicular area. (H&E)

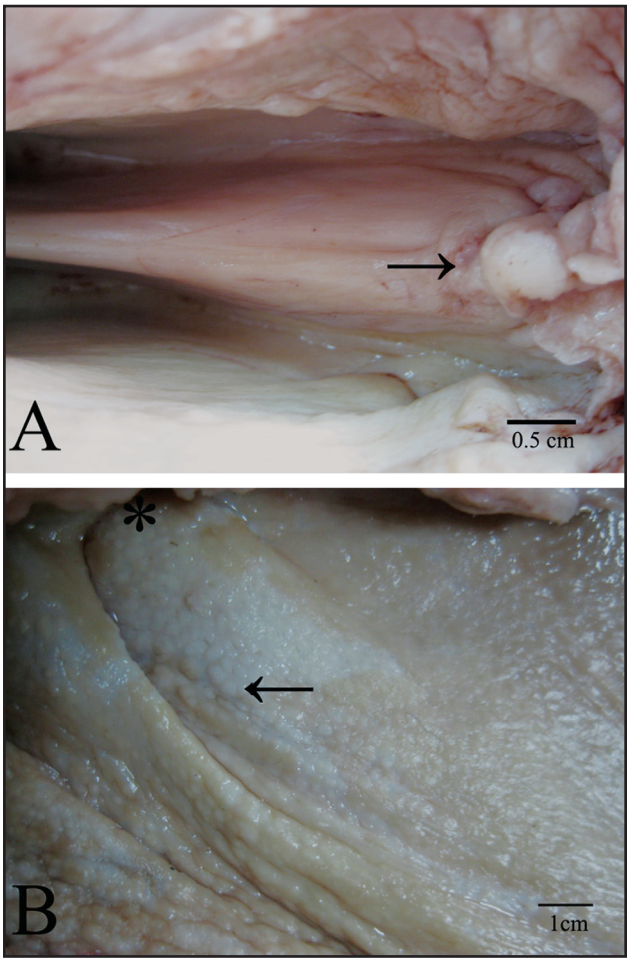

Fig 7. A: Ventral view of the pharyngeal tonsil after sectioning the soft palate in the median plane; B: Appearance of nasal lymphoid nodules after exposure to glacial acetic acid. Nodules appear as opaque white foci (arrow) and are clustered posterior to the opening of the Eustachian tube (star)).

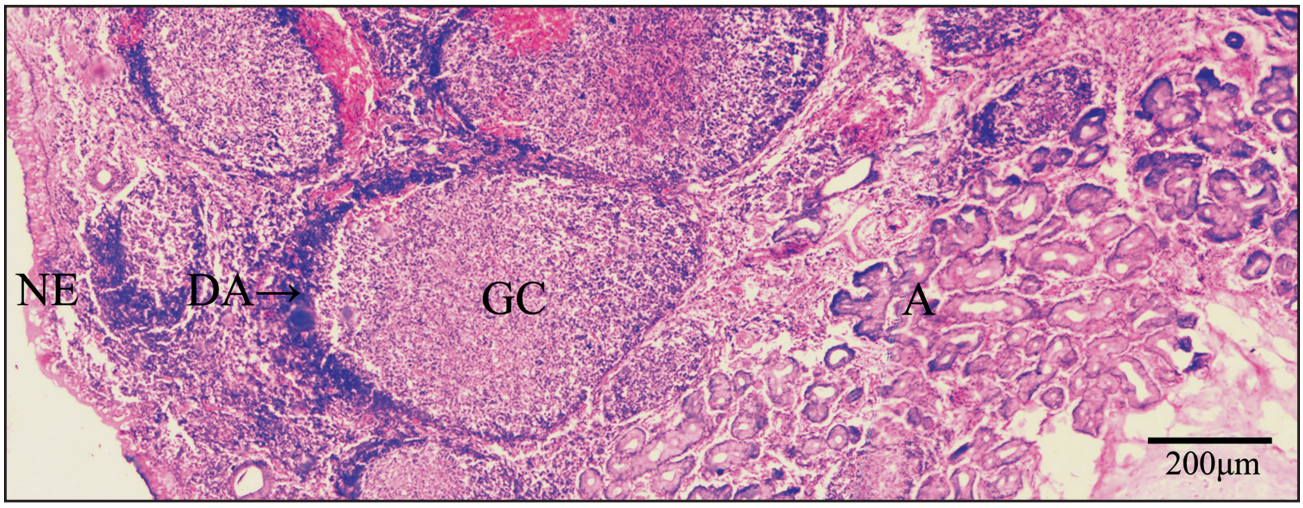

Fig 8. Histological section of the pharyngeal tonsil. Note the numerous secondary lymph nodules (arrows), the acinus (A) and non-lymphocyte infiltrated epithelium (NE) (H&E).

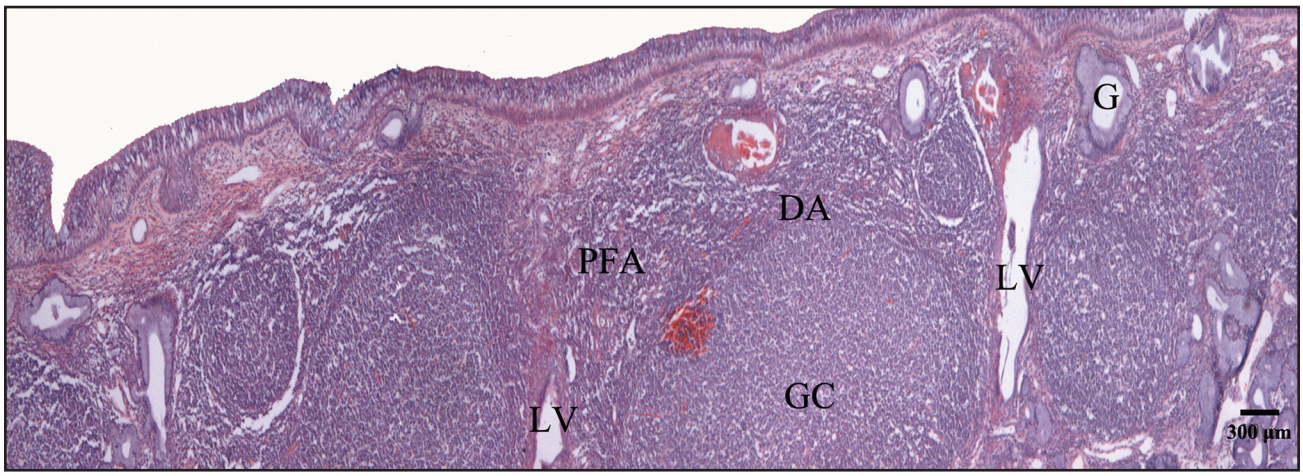

Fig 9. Histological section of the tubal tonsil showing dome area (DA), germinal centers (GC), parafollicular area (PFA), lymph vessels (LV) and glandular tissue (G). (H&E)

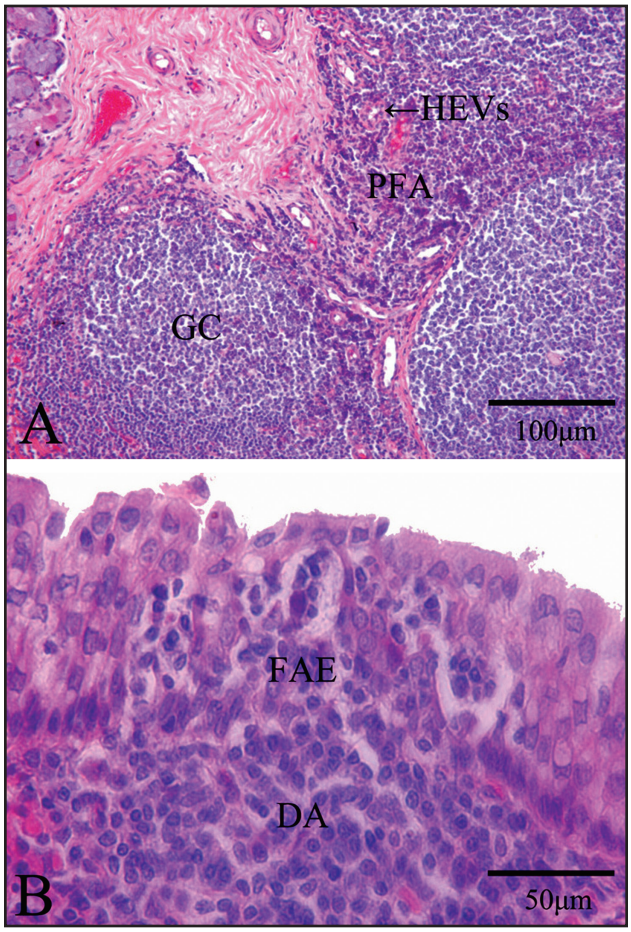

Fig 10. A: Histological section of the tubal tonsil showing parafollicular area (PFA), high endothelial venules (HEVs) and germinal centers (GC); B: pseudostratified columnar ciliated epithelium (E) as its transitions into FAE. (H&E)

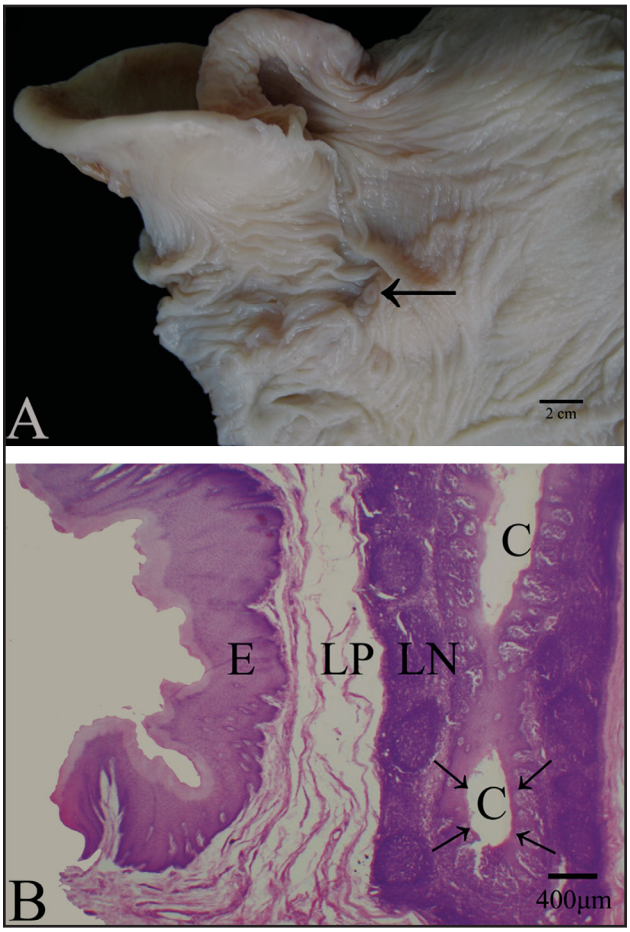

Fig 11. A: Lateral view of the larynx showing the paraepiglottic tonsil (black arrow); B: Histological section of the paraepiglottic tonsil showing epithelium (E), lamina propria (LP), lymphoid nodules (LN) and crypt (C). (H&E)

of reticular and a few collagen fibres except in places where there was mixing of lymphoid cells (Fig 6-B). Depressions on the outer free surface led into holes or small crypts with small openings. Well-developed holes were observed between primary and secondary lymph nodules (Fig 6-A).

The pharyngeal tonsil

The pharyngeal tonsil was located in the roof of the pharynx on the caudal part of the pharyngeal septum. The length, width and height of the tonsil were about 20 mm, 15 mm and 10 mm, respectively. No crypts and obvious folds were observed on the smooth surface of the tonsil. After fixation in 2% acetic acid, a number of opaque white spots became visible on the surface of the tonsil (Fig 7-A). It was covered by a folded keratinised stratified squamous epithelium. A large number of primary and secondary lymph nodules were observed in lamina propria mucosae. Most of the nodules had germinal centres but only a few had darkly stained coronae facing the epithelium. The epithelium overlying secondary lymph follicles was often heavily infiltrated by lymphocytes. Epithelium without goblet cells was irregularly modified into FAE having stratified features with a characteristic reduction in cell height, loss of cilia, infiltration of lymphocytes and absence of goblet cells. A few blood capillaries and venules were distributed irregularly especially in the interfollicular area. Lymphatics were not identified. Clusters of seromucous acini were scattered in the deeper lamina propria mucosae (Fig 8).

The tubal tonsil

After fixation in 2% acetic acid, scattered nodules were observed along the margins and around the associated flap of the slit-like pharyngeal openings of the eustachian tube on each side (Fig 7-B). The number of these nodules on each side varied from 60 to 140. The borders of the tubal tonsil could not be clearly distinguished using histology since scattered lymphoid cells are universally present in the lamina propria and tela submucosa throughout the respiratory tract. The surface of the tubal tonsil was lined by pseudostratified columnar ciliated epithelium. The oval to elongated nuclei of basal cells were linearly arranged towards the basement membrane with their longitudinal axis parallel to the height of the epithelium. The epithelium covering the lymphoid tissue was sometimes infiltrated by lymphocytes. A large number of primary and secondary lymph nodules were observed in lamina propria mucosae of ventral and close to the pharyngeal opening of the auditory tube (Fig 9). The epithelium was modified in places into FAE with abundant lymphoid cells near the surface and lacking cilia (Fig10-B). The basement membrane was irregular and interrupted. HEVs were located towards PFA (Fig 10-A).

The paraepiglottic tonsil

The paraepiglottic tonsil was located lateral to the epiglottis in the ventromedial segment of the pharyngeal sidewall. Per tonsil was made up of 3 to 8 nodular elevations with 2 or 3 narrow elongated entrances to the underlying crypts (Fig 11-A). Length of the tonsil varied from 2 to 10 mm and width from 2 to 5 mm. Histology revealed that the elevations consisted of aggregations of lymph nodules surrounded by parafollicular tissue and encapsulated by connective tissue from which septa extended into the larger nodules. Crypts were present in 9 out of the 32 aggregations which were observed in the 10 tonsils examined. The paraepiglottic tonsil was covered by a folded keratinised stratified squamous epithelium which was often heavily infiltrated by lymphocytes. Most of the lymph nodules were secondary nodules. Primary lymph nodules were the most obvious at the periphery of the aggregations (Fig 11-B).

Discussion

In the adult Bactrian camel six tonsils are present: the palatine, the lingual and the tonsil of the soft palate in the oropharynx, the pharyngeal and the tubal tonsils in the nasopharynx, and the paraepiglottic tonsil in the laryngopharynx. The palatine, pharyngeal and paraepiglottic tonsils are clearly distinguishable from the surrounding tissue. The tubal tonsil and the tonsil of the soft palate were macroscopically visible after fixation in 2% acetic acid. The lingual tonsil could not be located by any macroscopic landmarks, even with fixation in 2% acetic acid.

The palatine tonsils of the Bactrian camel is uniquely formed of aggregations of separate spherical nodules, which resembles that of the one humped camel and differs from other species (Liebler-Tenorio and Pabst, 2006; Zidan and Pabst, 2009). This arrangement increases the surface area of the tonsils. The palatine tonsils of the Bactrian camel can be classified as tonsils with crypts, similar to the one humped camel, humans, ruminants, horses, and swine but different from carnivores which lack crypts (Zidan and Pabst, 2009). The crypts play an important role in immune responses by specialised cells similar to M cells in the epithelium of Peyer's patches, as shown for rabbit tonsils (Gebert *et al,* 1995) and these will be relevant for trapping antigens (Nave *et al,* 2001). Each nodule contains only one to two crypts which increase the epithelial surface area potentially exposed to antigen (Casteleyn *et al,* 2008a). Also the presence of one or two crypts in each nodule

indicates that the camel palatine tonsils possess a large number of crypts bringing all the lymphoid follicles into close contact with reticulated epithelium of the crypts to magnify the immune response of the lymphoid follicles to antigen. Thus, the camel palatine tonsil plays a greater immunological role than tonsils without crypts or tonsils with a limited numbers of crypts found in other species (Casteleyn *et al,* 2007). The branched crypts in the bactrian camel are in contrast to the one humped camel (Zidan and Pabst, 2009). The lymphoid tissue constitutes the majority of tonsillar nodules and is organised into lymphoid follicles with clear germinal centres and interfollicular lymphoid tissue obviously separated. This is similar to the palatine tonsils of other species (Perry and Whyte, 1998; Kumar and Timoney, 2005). The lymphoid tissue constitutes the majority of tonsillar nodules and is organised into lymphoid follicles with clear germinal centers and interfollicular lymphoid tissue was obviously separated. This is similar to the palatine tonsils of other species (Perry and Whyte, 1998; Kumar and Timoney, 2005). The clear germinal centres indicate the active role of camel palatine tonsils in the immune response. Similar to the one humped camel, the interfollicular regions were rich in HEVs which mediate the extravasation of recirculating cells into lymph nodes (Perry and Whyte, 1998; Kumar and Timoney, 2005). Clusters of mucous glandular acini were observed among the nodules of camel palatine tonsils. An opening of the glands into the crypts was never seen, which is in accordance with the one humped camel and horses (Perry and Whyte, 1998; Kumar and Timoney, 2005; Zidan and Pabst, 2009).

The surface of the pharyngeal tonsil in the bactrian camel was lined by pseudostratified columnar ciliated epithelium. The epithelium overlying secondary lymph follicles was irregularly modified into FAE, without goblet cells having stratified features with a characteristic reduction in cell height, loss of cilia, infiltration of lymphocytes and absence of goblet cells. FAE shared histological features with bronchus-associated lymphoid tissue (BALT) and other MALT in different species of domestic and laboratory animals (Chen *et al,* 1989; Giannasca *et al,* 1997; Kumar and Timoney, 2001). The FAE is involved in transcytosis of antigens, transportation of immunocytes, and mucosal protection (Brandtzaeg and Halstensen, 1992). Epithelial cells also produce secretory component and polymeric Ig receptor, which stabilises and transports secretory IgA to the mucosal surface (Korsrud and Brandtzaeg, 1981). Intraepithelial lymphocytes were observed in the epithelium of pharyngeal tonsil of the bactrian camel. However, their number increased markedly at the base of the FAE. The regular feature is in accordance with the horse (Chen *et al,* 1989; Giannasca *et al,* 1997; Kumar and Timoney, 2001). Intraepithelial lymphocytes may originate from the underlying lamina propria as reported in gut-associated lymphoid tissue (GALT) of swine (Chu *et al,* 1979). The structure of the parafollicular area and the central nodular area were similar to those described in other species (Liebler-Tenorio and Pabst, 2006). The topography and the microscopic structure of pharyngeal tonsil in the camel suggested that they act as mechanisms for trapping and sampling antigens in the airstream (Mair *et al,* 1987).

In contrast to the bovine lingual tonsil which is clearly macroscopically visible and consists of numerous tonsillar follicles, the lingual tonsil cannot be determined macroscopically in the bactrian camel, which is similar to the sheep (Cocquyt *et al,* 2005). Only a few scattered aggregations of lymphoid cells are present in the lingual tonsil of the bactrian camel. This lymphoid tissue has a typical distribution on the lingual surface and is more abundant at this location than in the other parts of the tongue. So, we can refer to the describing of lingual tonsil in sheep, it is justified to use the term ''lingual tonsil'' also in the bactrian camel. Lymphatic tissue was found beyond the bovine lingual tonsils macroscopical outline . The follicular dendritic cells (FDC) were chosen as an identification parameter for tonsils, because FDC characterise the tonsillar lymph nodules and distinguish them structurally from unspecific accumulations of lymphocytes (Rebmann and Gasse, 2008).

The tonsil of the soft palate cannot be determined macroscopically in the bactrian camel. The structure of the tonsil composed of primary and secondary lymph nodules and aggregations of lymphocytes. On the ventral (oral) surface of the soft palate, no macroscopic signs of this tonsil were observed, which is in accordance with the ovine and porcine tonsil of soft palate (Belz and Heath, 1996; Cocquyt *et al,* 2005). Depressions on the outer free surface led into holes or small crypts with small openings (Kumar and Timoney, 2006). Well-developed crypts were not observed in the tonsil, the epithelial holes were observed between primary and secondary lymph nodules, which were similar to the horse and in contrast to the pig (Belz and Heath, 1996). The epithelial holes in the tonsil

of the soft palate (Olah and Everett, 1975) have been attributed to mechanical rupture because of the force of deglutition and/or microulcerations associated with bacterial activity. These holes may be dynamically formed, repaired and reformed under the influence of bacterial activity with the reciprocal formation of germinal centres (Nair and Rossinsky, 1985).

The tubal tonsil of the bactrian camel are not macroscopically distinguishable from the surrounding tissue. After fixation in acetic acid, scattered nodules were observed along the margins and around the associated flap of the slit-like pharyngeal openings of the eustachian tube on each side. These nodules may participate in antigen sampling of agents with potential to infect the guttural pouch or inner ear (Mair et al, 1988). The surface of the tubal tonsil was lined by pseudostratified columnar ciliated epithelium with folds and crypts (Mair et al, 1987; Perry and Whyte, 1998), which provide enhanced opportunities for antigen entrapment and attachment as in the nasopharyngeal tonsil. The FAE is responsible for uptake and absorption of soluble antigens by pinocytosis and for transport of particulate material to immunocytes in the subepithelial lymphoid tissue and by lymphatic drainage to regional lymph nodes (Kumar and Timoney, 2001). The tubal tonsil consisted of primary and secondary lymph nodules with clear germ centre, darkly stained coronae facing the epithelium and HEVs in PFA, which were similar to other tonsils in the camel and in accordance with humans, ruminants, pig and the horse (Kumar and Timoney, 2005).

The paraepiglottic tonsil is a part of the integrated pharyngeal mucosal immune system. Paraepiglottic tonsils were readily visible macroscopically and bilaterally present at the base of the epiglottis in the camel. They consisted mainly of secondary lymph nodules and were encapsulated in dense connective tissues. The results are in accordance with previous reports (Cocquyt *et al,* 2005). The bovine larynx, although it is devoid of a proper tonsil, can probably still organise a local immune response due to the presence of LALT (Cocquyt *et al,* 2005). The paraepiglottic tonsil and LALT are composed the integrated mucosal immune system in larynx of the camel (Yang et al, 2010). The crypts in the paraepiglottic tonsil increase the epithelial surface area potentially exposed to antigen (Casteleyn *et al,* 2008b) and protection to the laryngopharynx. Because of the adjacent anatomical position, the palatine and paraepiglottic tonsils were lined with stratified squamous epithelium, which resembles that of sheep (Casteleyn *et al,* 2010).

In summary, six tonsils are present in the adult Bactrian camel. They have the cytologic basis of normal mucosal reaction which may play a major role in immune responses.

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