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A HISTOLOGIC AND HISTOMORPHOMETRIC STUDY OF THE FIRST COMPARTMENT OF STOMACH IN THE DROMEDARY (*Camelus dromedarius*)

Ahmad Al Aiyan[1], Kenneth Richardson[2], Turke Shawaf[3], Saqib Abdullah[1], Robert Barigye[1], Al Aiyan A.[1], Richardson K.[2], Shawaf T.[3], Abdullah S.[1] and Barigye R.[1]

[1]Department of Veterinary Medicine, College of Food and Agriculture, United Arab Emirates University, Al Ain, UAE
[2]College of Veterinary Medicine, School of Veterinary and Life Sciences, Murdoch University, Perth, Australia
[3]Department of Clinical studies, College of Veterinary Medicine, King Faisal University, Al-Hasa, Saudi Arabia

ABSTRACT

In this study, tissue samples from 2 glandular and 2 non-glandular regions of the stomach's first compartment (C1) were collected from 48 healthy dromedaries of 4 age groups; 1 - 4 years, 5 - 7 years, 8 - 11 years and 12 - 16 years. After fixing in 10% buffered formalin, the specimens were processed routinely, stained with H&E and their histology examined and the thickness of the different layers measured. The histological data were similar to those previously reported whilst the histomorphometric data revealed significant intergroup variation (p=0.001) in the thickness of all layers in the caudodorsal glandular sac and the cranioventral non-glandular sac of C1 compartments. However, in the cranioventral glandular sac, the mucosal thickness was insignificant (p>0.05) and in the caudodorsal non-glandular sac the thicknesses of the mucosa, circular layer of the muscular layer and serosa were insignificant (p>0.05) in the different age groups. This study showed that the histological layers in the different regions of the first compartment of the dromedary stomach gradually increase in thickness with the animal's age.

Key words: Camel, dromedary, forestomach, glandular sac histology, histomorphometry

The true ruminants have a four-chambered stomach but camels have a three compartmented stomach consisting of a 'rumen', 'reticulum' and the 'abomasum' (Allouch, 2016; Eerdunchaolu *et al,* 1999; Langer, 1988; Singh *et al,* 1996; Vallenas *et al,* 1971; Wang *et al,* 2000). Whilst camelids do ruminate, their different stomach form has resulted in the camel being classified as a pseudoruminant (Eerdunchaolu *et al,* 1999; Langer, 1988; Singh *et al,* 1996; Vallenas *et al,* 1971; Wang *et al,* 2000). Confounding the different nomenclatures in use for the pregastric chambers of the camelid's stomach complex, several authors have reported a 4th chamber the 'omasum' (Czerkawski, 1985; Hansen and Schmidt-Nielsen, 1957; Hegazi, 1950; Smuts and Bezuidenhout, 1987). Reflecting the nomenclature that still exist in 2 recent studies of the bactrian camel stomach, Eerdunchaolu *et al (*1999) reported three compartments C1, C2 and C3, while Wang *et al (*2000) reported 2 ventricles and an abomasum. In their studies of the dromedary stomach, Abuagla *et al (*2014) and Osman (1999) reported 4 compartments namely C1, C2, C3 and C4. More recently, Pérez *et al (*2016) reported 3 compartments C1, C2 and C3 in the dromedary stomach.

In ruminants; the rumen, reticulum and omasum are nonglandular and lined by a keratinised stratified squamous epithelium while the abomasum is glandular (Banks, 1993; Eurell and Dellman, 1998). However, while most of the camel's first pregastric compartment is lined primarily by a nonglandular mucosa of keratinised stratified squamous epithelium, there are 2 large separate, distinct, glandular areas. The nomenclature used for these structures is varied ranging from; craniodorsal sac area and ventral sac area (Hansen and Schmidt-Nielsen, 1957), to glandular sac of cranioventral sac and glandular sac of caudodorsal sac (Smuts and Bezuidenhout, 1987), anterior and posterior glandular sac areas (Eerdunchaolu *et al,* 1999), cranial and caudal glandular sac areas (Wang *et al,* 2000) as well as cranioventral and caudodorsal glandular sacs (Abuagla *et al,* 2014). Other studies report 3 glandular areas (water sacs) in the camel rumen,

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that also have a variety of designations ranging from; 1st, 2nd and 3rd water sacs (Hegazi, 1950) to cranioventral, caudodorsal and caudoventral water sacs (Allouch, 2016). Historically, the glandular areas were considered to play a role in the storage of water (Hegazi, 1950) but this was later disproven (Hansen and Schmidt-Nielsen, 1957). Earlier studies reported that the non-glandular region of the camel rumen, C1 of this study, was lined by keratinised stratified squamous epithelium and that the glandular regions were characterised by a simple columnar epithelium (Abdel-Magied and Taha, 2003; Amasaki *et al,* 1988; Hansen and Schmidt-Nielsen, 1957).

Many histomorphometric studies of the stomach complex have been reported in different ruminant species including cattle (Banks, 1993; Eurell and Dellman, 1998; Vivo *et al,* 1990), buffaloes (Sengar and Singh, 1970; Taluja and Saigal, 1988; Tiwari and Jamdar, 1970), goats (Chungath *et al,* 1985), sheep (Franco *et al,* 1992; Poonia *et al,* 2011) and reindeer (Mathiesen *et al,* 2000). Likewise, there have been numerous histomorphometric studies of the camel stomach complex (Abdel-Magied and Taha, 2003; Abuagla *et al,* 2014; Hansen and Schmidt-Nielsen, 1957; Naghani and Akradi, 2011). However, a comprehensive evaluation of histomorphometric changes in the histological layers of adult camel forestomach has not been reported. The aim of this study is to describe the histological characteristics of the mucosa, submucosa, muscularis and serosa of the dromedary's first stomach compartment. In addition, age-related histomorphometric changes were evaluated in animals aged from 1 to 16 years.

Materials and Methods

Study animals

The tissue samples for this study were taken from 48 healthy dromedaries of both sexes aged between 1 to 16 years old. In accordance with the research ethics code of the United Arab Emirates University Animal Ethics Committee, tissue samples were collected from camels slaughtered for food at the municipal slaughterhouse, Al Ain, Emirate of Abu Dhabi, UAE. Prior to slaughter, the age of the study animals was estimated by examining their dentition (Rabagliati, 1924). Based on age, 12 camels were assigned to each group where; Group 1 (1 - 4 years), Group 2 (5 - 7 years), Group 3 (8 - 11 years) and Group 4 (12 - 16 years). Immediately after slaughter, a 5×5 cm tissue sample was collected from the cranioventral non-glandular sac (CVNGS), cranioventral glandular sac (CVGS), caudodorsal non-glandular sac (CDNGS) and caudodorsal glandular sac (CDGS) of the first stomach compartment (Fig 1). The specimens were placed immediately in 10% buffered formalin and held at room temperature for at least 2 weeks prior to histological processing.

Tissue processing and staining

Following fixation, samples were trimmed to approximately 1.5×2.5 cm, placed into prelabelled tissue cassettes and loaded onto a spin tissue processor STP 250-VR (Pantigliate, Milan, Italy). The samples were processed routinely and 5 µm transverse sections were made using a YD-355AT microtome (Jinhua City, Zhejiang Province, China). The tissue ribbons were mounted onto microscopic slides, stained routinely with haematoxylin and eosin (H&E).

Light microscopy, histomorphometric and statistical analysis

A detailed histological evaluation of the H&E stained tissue sections was done using a light microscope (Olympus light microscope BX53, Japan). Each section was examined using 10x, 40x and 60x objectives, starting from the lumen and then scanning across the; tunica mucosa, tela submucosa, tunica muscularis, to the tunica adventitia. All histological features including the type of epithelium, connective tissue, blood and lymphatic vessels, autonomic nerve ganglia, smooth muscle and adipose tissue were examined. The thickness of the different histological layers were measured with the aid of an Olympus light microscope (BX53, Japan). An analysis of variance using Statistical Packages for Social Sciences software (SPSS Inc. Version 20, Chicago IL, USA) was conducted on all thickness data. The mean of the intergroup variation in the thickness of the different histological layers were calculated using Duncan's multiple range test and the differences in the dimensions of the different histological layers were considered significant at $p<0.05$.

Results and Discussion

Macroscopic assessment of the camel stomach

In the present study, a comprehensive gross and microscopic assessment of the camel stomach demonstrated that the stomach of the camel is divided into 3 compartments namely C1, C2 and C3 (Fig 1A and B). Compartment 1 is the largest and occupies most of left side of the abdominal cavity. Its parietal surface abuts the diaphragm and left abdominal wall while its visceral surface is oriented to the right and is related to C2, C3, liver

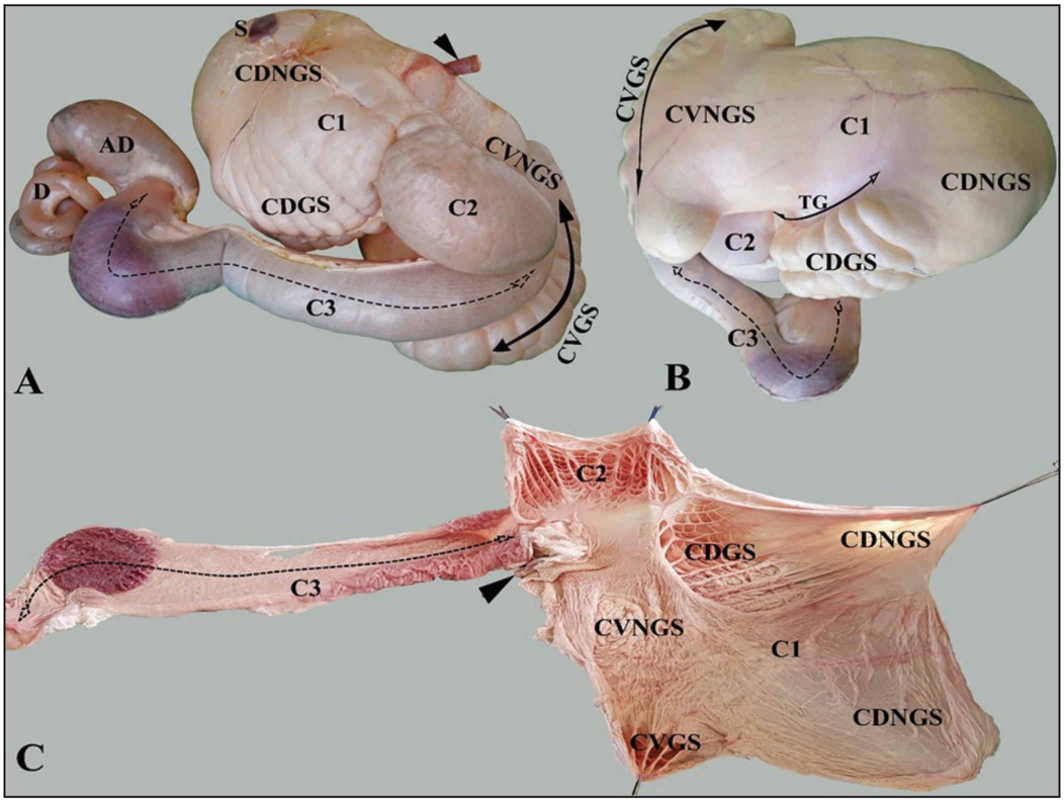

Fig 1. Composite photograph of the gross anatomy of the dromedary stomach complex where (A) right visceral aspect placed in its correct topographical position in the abdominal cavity, (B) ventral view and (C) luminal view of a dissected stomach complex. Here (C1) is the first compartment, (C2) second compartment, (C3) (interrupted black arrows) third compartment, (CDGS) caudodorsal glandular sac, (CDNGS) caudodorsal nonglandular sac, (CVGS) cranioventral glandular sac, (CVNGS) cranioventral nonglandular sac, (TG) transverse groove, (AD) ampulla duodeni, (D) duodenum, (S) spleen, (black arrowheads) oesophagus.

and intestines. The dorsal border of C1 lies against the diaphragm and the roof of the abdominal cavity, where the oesophagus opens craniodorsally into C1 (Fig 1A). The ventral border of C1 follows the contour of the abdominal floor. Topographically, C1 is divided by a strong oblique transverse groove into cranioventral and the caudodorsal sacs, in each of which a glandular sacculated area, namely cranioventral and caudodorsal glandular sacs, are situated (Fig 1A and B). Internally the nonglandular regions are characterised by laminae-like mucosal folds lined by stratified squamous epithelium whilst the glandular sacs are characterised by a retiform appearance, where robust radiating pillars (some being up to 1.5 cm in height) extend across the sac (Fig 1C). These pillars are connected by numerous cross struts forming a series of deep, mostly rectangular subcompartments (cells) that are lined by glandular mucosa characterised by rugae that are lined by a simple columnar epithelial cells.

The 2nd compartment (C2) is ovoid in shape, situated to the right and cranioventral to the cardia, directly cranial to the caudodorsal glandular sac of C1 (Fig 1A). Compartment 2 is separated externally from C1 by a small deep groove. Internally, the orifice between the C1 and the C2 is located cranial to the caudodorsal glandular sac of C1 and appears large compared to the small constricted orifice that connects C2 with C3 (Fig 1A and C). The elongated tubular 3rd compartment (C3) originates from C2 and lies cranially on the dorsal surface of the cranioventral sac and traverses caudally across the right side of C1 to merge with a small 'true' gastric gland region, immediately cranial to the duodenum (Fig 1A and B).

Histology of the non-glandular caudodorsal and cranioventral sacs

In all age groups, the non-glandular regions of (C1) of the dromedary stomach were characterised by a tunica mucosa, tela submucosa, tunica muscularis and tunica adventitia (Figs 2 and 3). The tunica mucosa has a luminal stratified squamous keratinised epithelium overlying a series of mucosal folds of varying height. Its epithelium is many cells thick and has a basal layer that is organised into

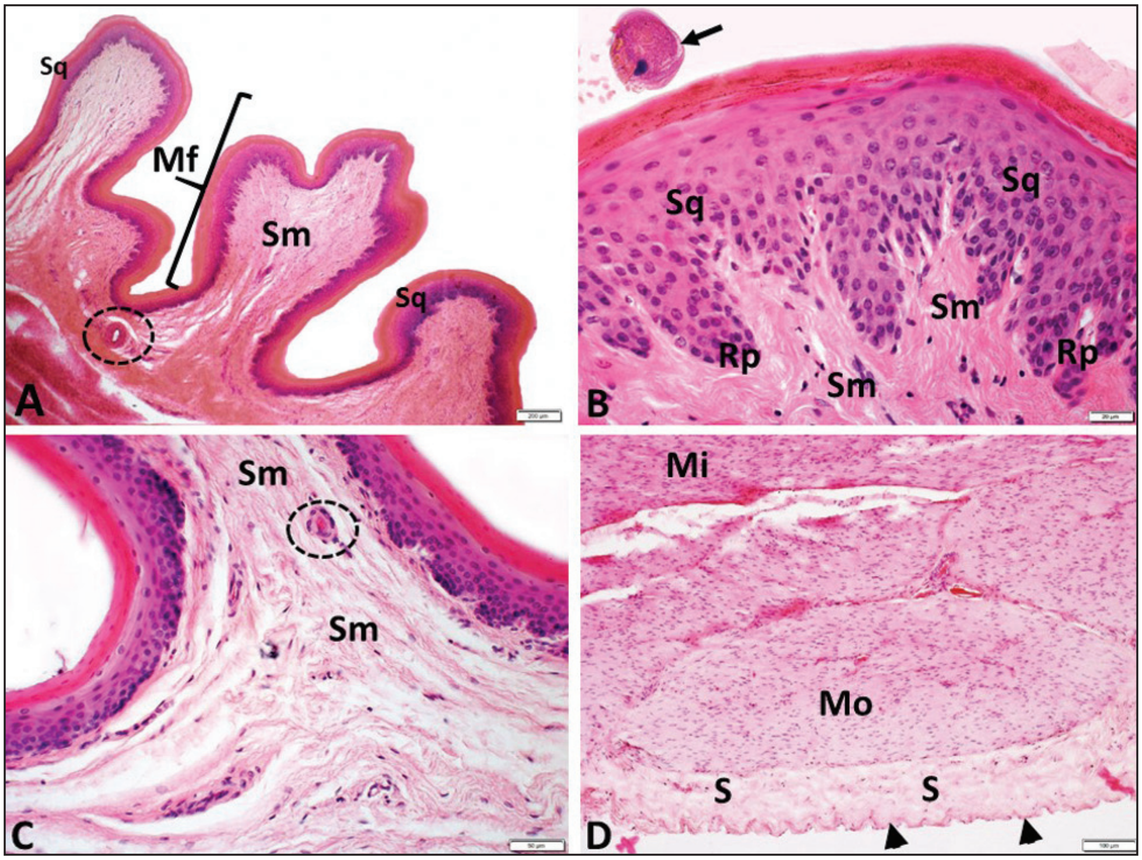

Fig 2. Light microscopy of the caudodorsal nonglandular sac where (A) mucosal folds, (B) mucosa, (C) base of a mucosal fold and (D) tunica muscularis and adventitia. Note the thick complex stratified squamous epithelium (Sq) covering the mucosal folds (Mf), the basal layer of the stratified squamous epithelium organised into short and stout downward projecting rete peg-like structures (Rp), (black arrow) *Balantidium* spp. symbiont, (Sm) tela submucosa with small blood vessels (interrupted black circles) in abundant connective tissue, (Mi) tunica muscularis circular and (Mo) tunica muscularis longitudinal, (S) adventitia with abundant connective tissue and lined by a simple squamous epithelium (black arrowheads). (H&E stain).

short, stout, peg-like structures extending into the adjacent submucosa. Occasional mitotic states are found within the basal layer. In addition, some keratinocytes located within the prekeratin layer have small amounts of intracytoplasmic keratohyalin granules (Fig 2B). The prekeratin layer gradually transitions into a parakeratotic keratin layer that is approximately one third of the entire thickness of the stratified squamous epithelium (Fig 2B and 3). Located within the lumen and attached to the epithelial surface were *Balantidium coli* like round to ovoid shaped protozoans (Fig 2B).

The submucosa occupying the core of the mucosal folds (Fig 2A, B and C) is characterised by large amounts of loose to moderately dense connective tissue that is rich in collagen fibres, numerous fibroblasts, a few small nerves, many blood vessels (Fig 3C), as well as several extensive adipose tissue deposits (Fig 3C). The tunica muscularis is composed of a broad inner circular and thinner outer longitudinal smooth muscle layer (Fig 2D and 3D). In the intervening region between the 2 smooth muscle layers there are; large amounts of connective tissue, moderate numbers of variably sized blood and lymphatic vessels, occasional post-ganglionic nerve fibres and clusters of ganglionic neuronal cells of the myenteric plexus, as well as adipose tissue deposits. The tunica adventitia has small accumulations of loose connective tissue interspersed with variably sized blood and lymphatic vessels all surmounted by a simple squamous epithelium.

Histology of the glandular caudodorsal and cranioventral sacs

In all age groups, the glandular sacs of C1 were characterised by a tunica mucosa, tela submucosa, tunica muscularis and tunica adventitia (Figs 4 and 5). The tunica mucosa bordering the lumen had a simple columnar epithelium, overlying the lamina propria and a distinct lamina muscularis mucosa. The mucosal surface was thrown into rugae that were lined by a glandular epithelium composed of

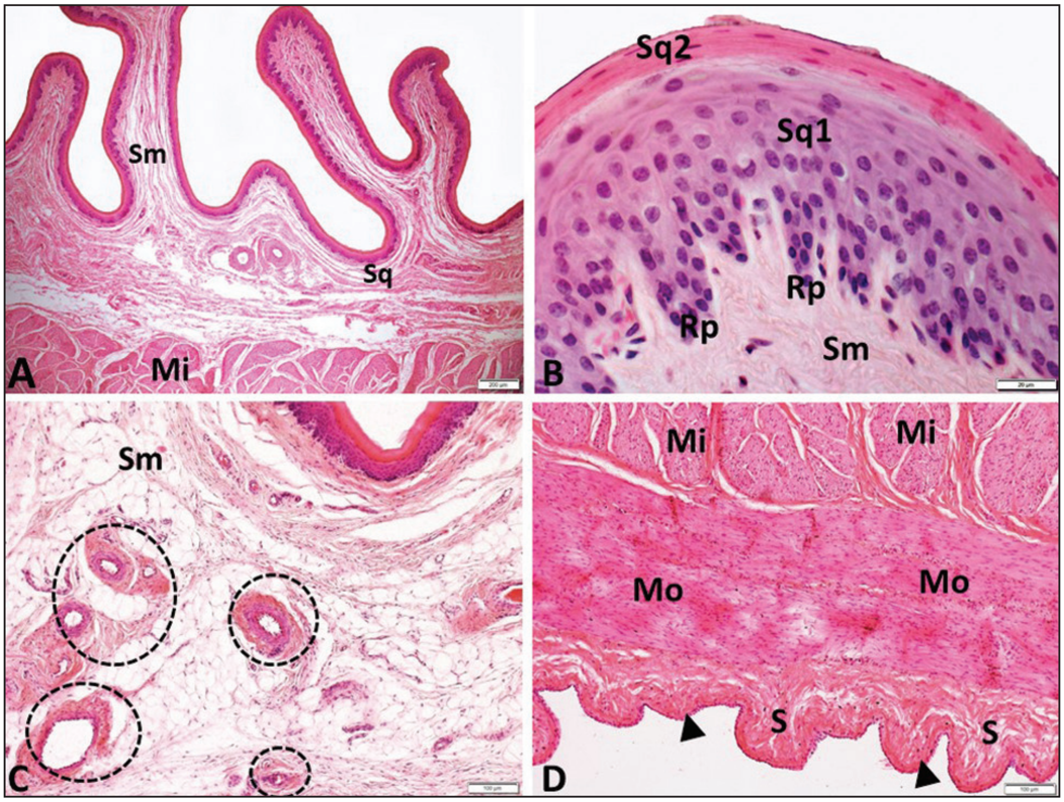

Fig 3. Light microscopy of the cranioventral nonglandular sac where (A) mucosal folds, (B) mucosa, (C) base of a mucosal fold and (D) tunica muscularis and adventitia. Where (Sq1) thick stratified squamous epithelium that gradually transitions into (Sq2) keratin layer, (Rp) rete peg-like structures of stratified squamous epithelium, (Sm) tunica propria submucosa with numerous blood vessels (interrupted black circles) and abundant adipose and loose connective tissue. (Mi) tunica muscularis circular and (Mo) tunica muscularis longitudinal. (S) adventitia characterised by abundant connective tissue and lined by a simple squamous epithelium (black arrowheads). (H&E stain).

numerous mucous neck cells supported by simple columnar epithelial cells seated on a barely visible basement membrane. The stomach glands were simple tubular and occasionally double branched sitting upon crypts that lied close to the lamina muscularis mucosae. The lamina propria had large numbers of lymphocytes, a few plasma cells together with scattered oeosinophils.

The tela submucosa (Figs 4A, C; Fig 5A, C) was an extensive area of loose connective tissue having many blood and lymphatic vessels, obvious neural plexuses, well defined lymphatic aggregations as well as extensive local adipose deposits. The tunica muscularis had a broad inner circular layer and a narrower outer longitudinal layer. The interstitial areas between the circular and longitudinal muscle layers was characterised by small amounts of loose connective tissue in which blood vessels, clumps of parasympathetic ganglion cells and postganglionic fibres as well as small deposits of adipose tissue occur. The tunica adventitia (Figs 4D and 5D) had small amounts of collagen-rich connective tissue in which occasional fibroblasts, large numbers of large lymphatic vessels and small numbers of variably sized blood vessels were present. The outer layer, the tunica serosa, is a simple squamous epithelium (Figs 4D and 5D).

Histomorphometric and statistical analyses

Caudodorsal non-glandular sac

There was statistically significant intergroup variation in the thickness of the tela submucosa and the longitudinal smooth muscle layer (p=0.0001). Thickness were least in the 1-4-year-olds and maximal 12-16-year-olds (Table 1). However, the thickness of the mucosa (p=0.080), muscularis circular layer (p=0.958) and adventitia (p=0.060) did not show significant intergroup variation (Table 1).

Caudodorsal glandular sac

The thickness of the mucosa, submucosa, tunica muscularis and adventitia in the CDGS showed significant intergroup variation among the 4 groups (Table 2). The thickness of all the histological layers increased progressively with the animal's age (Table 2).

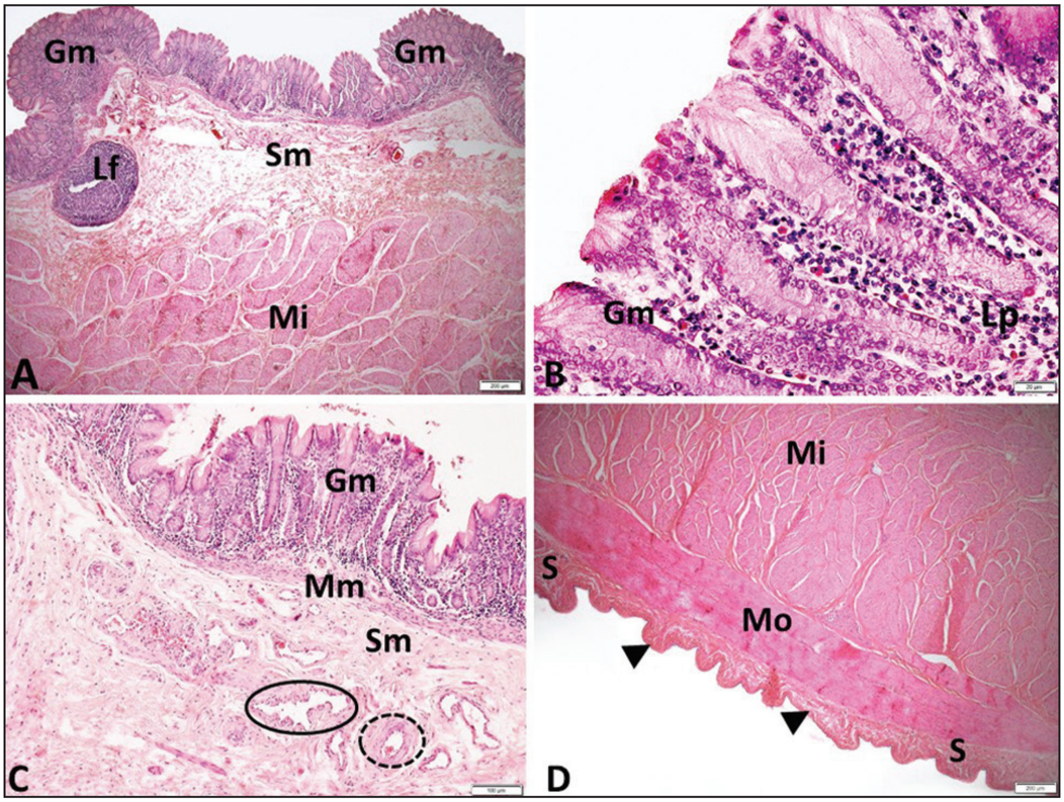

Fig 4. Light microscopy of the caudodorsal glandular sac where (A) over view, (B) mucosa, (C) mucosa and submucosa (D) tunica muscularis and adventitia. Note the glandular mucosa is organised into folds lined by a simple columnar epithelium that is rich in mucous producing cells (Gm). Lamina propria (Lp) is infiltrated by numerous lymphocytes, a few plasma cells along with occasional oeosinophils; muscularis mucosae (Mm). The tunica submucosa (Sm) has numerous blood (interrupted black circles) and lymphatic vessels (solid circles) within loose connective tissue. The tunica muscularis has circular (Mi) and longitudinal (Mo) layers. The adventitia (S) is lined by a simple squamous epithelium (black arrowheads). A single lymphoid follicle (Lf) is present in the submucosa. (H&E stain).

Cranioventral non-glandular sac

The thicknesses of the mucosa, submucosa, circular smooth muscle layer and the tunica adventitia of the CVNGS showed significant intergroup variation with thickness gradually increasing from the youngest to the oldest animals (Table 3). The muscularis longitudinal layer was significantly thicker in group 4 with decreasing thickness in groups 2, 1 and 3, respectively.

Cranioventral glandular sac

The mucosal thickness of the CVGS was similar in all groups (Table 4). However, the submucosal thickness varied significantly with age where maximal thickness occurred in the older animals and least in the youngest animals. The thickness of the muscularis circular layer had significant intergroup variation with the maximum thickness observed in group 2, followed by groups 4, 3 and 1, respectively. The thickness of the muscularis longitudinal layer also showed significant intergroup variation with maximum values observed in group 4 followed by groups 2, 3 and 1, respectively. The thickness of the adventitia increased significantly with age (Table 4).

Many studies have described the gross morphological features (Abdel-Magied and Taha, 2003; Abuagla *et al,* 2014; Osman, 1999; Smuts and Bezuidenhout, 1987; Wang *et al,* 2000) and others have reported the histological differences in the mucosal layers of the individual anatomical compartments of the camel stomach (Abdel-Magied and Taha, 2003; Dougbag and Berg, 1980; Eerdunchaolu *et al,* 1999; Hansen and Schmidt-Nielsen, 1957; Hegazi, 1950).

Conflicting interpretations and varying nomenclatures have arisen in the attempts to make a direct comparison between the stomach complex of the camel and that of ruminants. To highlight these inconsistencies, some researchers classified the camel as a pseudoruminant on the basis of a 3 compartment stomach (Abdel-Magied and Taha, 2003; Allouch, 2016; Dougbag and Berg, 1980; Eerdunchaolu *et al,* 1999; Pérez *et al,* 2016; Vallenas *et al,* 1971; Wang *et al,* 2000). On contrary,

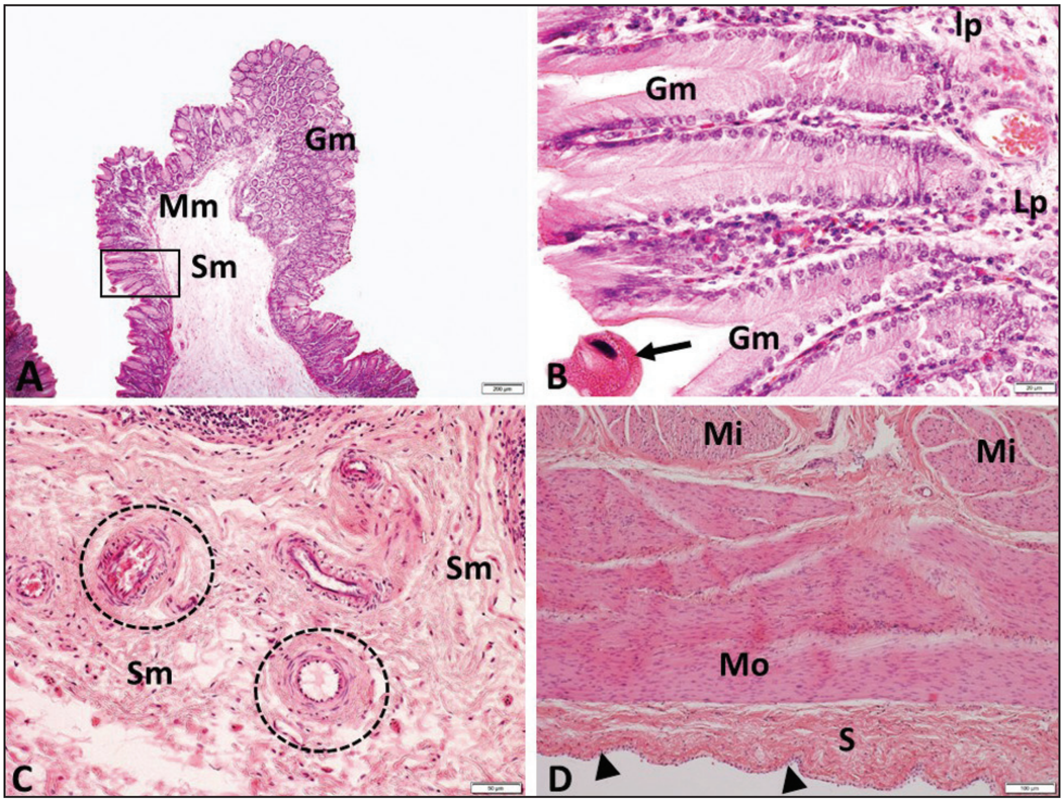

Fig 5. Light microscopy of cranioventral glandular sac where (A) mucosal fold, (B) mucosa, (C) base of a mucosal fold, (D) tunica muscularis and adventitia. Note the glandular mucosa is organised into folds lined by simple columnar epithelium (Gm) with many mucous neck cells. The lamina propria (Lp) has numerous lymphocytes, few plasma cells and occasional oeosinophils. (Mm) muscularis mucosae, (Sm) tunica submucosa with numerous blood vessels (interrupted black circles) and loose connective tissue. The tunica muscularis has circular (Mi) and longitudinal (Mo) layers. The adventitia (S) is lined by a simple squamous epithelium (black arrowheads). Black arrow, a *Balantidium* sp. protozoan.

others have claimed that the camel stomach has 4 compartments (Abuagla *et al,* 2014; Hansen and Schmidt-Nielsen, 1957; Hegazi, 1950; Osman, 1999; Smuts and Bezuidenhout, 1987). However, none of the compartments of the dromedary stomach has a similar suite of histological features as is found in the rumen, reticulum, omasum and abomasum of cattle or sheep (Banks, 1993; Eurell and Dellman, 1998). Consequently, the dromedary's stomach compartments cannot be considered homologous with any of those of the ruminants. The present study has revisited the gross anatomical structure of the dromedary stomach and on the basis of our data, we have adopted the terms; 1st compartment C1, 2nd compartment C2 and the 3rd compartment C3. Similarly, according to the topographical position of the 2 divisions of C1, we have adopted the terms, caudodorsal and cranioventral sacs of C1.

In present study of the dromedary stomach, the mucosal surface of the nonglandular regions of C1 share microscopic characteristics with the ruminal mucosa of the Ruminantia. However, we found that the first compartment of the dromedary stomach is characterised by mucosal folds that are morphologically dissimilar to the ruminal papillae of the Ruminantia. This has been reported by other authors (Eurell and Dellman, 1998; Hansen and Schmidt-Nielsen, 1957; Tamate *et al,* 1971). This study confirms the presence of the mucosal folds of the dromedary's first forestomach compartment reported by Hansen and Schmidt-Nielsen (1957) and in the bactrian camel reported by Amasaki *et al* (1988). Previously, Tamate *et al* (1971) and Singh *et al* (1983) have reported that ruminal papillae in cattle serve to increase the surface area for the absorption of volatile fatty acids and electrolytes. It is logical to conclude that the laminae-like mucosal folds seen in the nonglandular areas of C1 of the dromedary may also serve similar physiological functions.

In the present study, the muscularis mucosae is absent from the nonglandular areas of C1, as has been reported for the forestomachs in a number of domestic ruminant species including cattle (Eurell and Dellman, 1998; Vivo *et al,* 1990), sheep (Franco

Table 1. Thickness of the layers of the non-glandular part of the caudodorsal sac of the rumen in different age groups.

Group	1 (1-4 year)	2 (5-7 year)	3 (8-11 years)	4 (12-16 year)	P-value
Mucosa	138.02 ± 12.40[a]	145.73 ± 12.46[ab]	163.48 ± 21.26[ab]	188.50 ± 8.45[b]	0.08
Submucosa	560.52 ± 26.85[a]	813.57 ± 38.62[b]	956.33 ± 48.39[c]	987.79 ± 41.02[c]	0.00
Inner circular	1068.91 ± 24.76[a]	1183.83 ± 35.10[b]	1152.32 ± 35.59[ab]	1151.65 ± 20.80[ab]	0.958
Outer longitudinal	666.16 ± 21.82[a]	680.93 ± 27.82[a]	760.41 ± 38.52[a]	920.48 ± 37.58[b]	0.00
Serosa	193.35 ± 13.85[a]	188.76 ± 18.71[a]	230.36 ± 23.31[ab]	254.09 ± 19.33[b]	0.060

Values with different superscripts in a row differ significantly ($p<0.05$).

Table 2. Thickness of the layers of the caudodorsal glandular sac of the rumen in different age groups.

Group	1 (1-4 year)	2 (5-7 year)	3 (8-11 years)	4 (12-16 year)	P-value
Mucosa	129.04 ± 6.08[a]	135.38 ± 9.566[a]	175.18 ± 7.23[b]	181.85 ± 8.80[b]	0.000
Submucosa	609.04 ± 46.47[a]	742.53 ± 36.38[b]	781.88 ± 40.43[b]	1012.02 ± 18.60[c]	0.000
Inner circular	9994.62 ± 36.26[a]	1089.06 ± 27.26[a]	1341.79 ± 44.80[b]	1661.63 ± 48.13[c]	0.000
Outer longitudinal	780.93 ± 23.32[a]	969.03 ± 37.34[b]	916.53 ± 36.23[b]	983.85 ±31.29[b]	0.000
Serosa	133.53 ± 8.01[a]	208.21 ± 15.18[b]	216.07 ± 10.04[b]	227.72 ± 14.57[b]	0.000

Values with different superscripts in a row differ significantly ($p<0.05$).

et al, 1992; Poonia *et al,* 2011) and buffaloes (Taluja and Saigal, 1988). However, the muscularis mucosae was reported to be present as scattered bundles of smooth muscle cells near the glandular sac areas of the dromedary (Hansen and Schmidt-Nielsen, 1957). The muscularis mucosae may be involved in the mixing and digestion of the food as well as acting as sphincters of the subcompartments (cells) found in the glandular regions of C1 to retain their contents, while contraction of the muscularis mucosae in the wall and floor of these cells causes evacuation of their contents. The structure of the tunica muscularis in the nonglandular sacs of the dromedary reported in this study is similar to that reported in dromedaries (Hansen and Schmidt-Nielsen, 1957) and all Ruminantia studied to date (Banks, 1993; Chungath *et al,* 1985; Eurell and Dellman, 1998; Franco *et al,* 1992; Poonia *et al,* 2011; Vivo *et al,* 1990). The present study found that the tunica serosa of the glandular sacs has an outer layer of simple squamous epithelial cells overlying an inner layer characterised by abundant loose irregular connective tissue sparsely interspersed with occasional fibroblasts, large numbers of large lymphatic vessels and low numbers of variably sized blood vessels. Similar findings have been reported in buffaloes and sheep (Poonia *et al,* 2011; Taluja and Saigal, 1988).

Glandular areas like those found in the forestomach of the dromedary are absent in domestic ruminant species including cattle (Banks, 1993; Eurell and Dellman, 1998; Vivo *et al,* 1990), buffaloes (Sengar and Singh, 1970; Taluja and Saigal, 1988; Tiwari and Jamdar, 1970), goats (Chungath *et al,* 1985) and sheep (Franco *et al,* 1992, Poonia *et al,* 2011). The mucosa in the CDGS and CVGS of the dromedary's first stomach compartment is a simple columnar epithelium rich in mucous neck cells. The mucosa is continuous with extensive simple straight tubular glands together with a few branched tubular glands. Well-developed muscularis mucosae is present in the glandular sacs of C1.

Similar to other livestock species, numerous variably sized blood vessels, myenteric plexuses and abundant adipose tissue are present in the intervening interstitial areas between the inner circular and outer longitudinal muscle layers. The tunica serosa showed histological features similar to those present in the non-glandular sacs including the presence of small blood capillaries, adipose tissue and abundant collagen fibres in the subserosa lined by simple squamous epithelial cells.

In the present study, the histomorphometric analysis of the non-glandular sacs of C1 of the dromedary stomach revealed significant intergroup variation as the mucosa, submucosa, inner circular muscular and the serosal layers were thicker in the CVNGS, while the longitudinal smooth muscle layer was thicker in the CDNGS in all groups. In the present study the maximum mucosal thickness was 226.01 μm in the CVNGS in animals aged 12-16 years

Table 3. Thickness of the layers of the non-glandular part of the cranioventral sac of the rumen in different age groups.

Group	1	2	3	4	P-value
	(1-4 year)	(5-7 year)	(8-11 years)	(12-16 year)	
Mucosa	122.82 ± 9.46[a]	141.65 ± 15.68[a]	186.46 ± 15.40[b]	226.01 ± 12.86[c]	0.000
Submucosa	942.97 ± 20.49[a]	974.72 ± 23.78[a]	1226.61 ± 22.74[b]	1466.05 ± 25.52[c]	0.000
Inner circular	1309.20 ± 47.75[a]	1280.19 ± 32.57[a]	1352.60 ± 43.74[a]	1623.80 ± 29.63[b]	0.000
Outer longitudinal	669.53 ± 23.60[a]	743.20 ± 20.08[b]	641.78 ± 16.58[a]	749.41 ± 21.46[b]	0.000
Serosa	205.94 ± 14.66[a]	257.50 ± 17.10[b]	268.38 ± 16.04[b]	273.95 ± 6.12[b]	0.005

Values with different superscripts in a row differ significantly ($p<0.05$).

Table 4. Thickness of the layers of the cranioventral glandular sac of the rumen in different age groups.

Group	1	2	3	4	P-value
	(1-4 year)	(5-7 year)	(8-11 years)	(12-16 year)	
Mucosa	157.43 ± 17.05[a]	193.73 ± 16.16[ab]	194.09 ± 12.49[ab]	200.43 ± 5.04[b]	0.115
Submucosa	673.50 ± 19.16[a]	717.54 ± 21.87[a]	867.08 ± 23.19[b]	967.45 ± 12.46[c]	0.000
Inner circular	1040.93 ± 31.84[a]	1295.09 ± 28.35[c]	1111.70 ± 43.70[ab]	1170.15 ± 20.67[b]	0.000
Outer longitudinal	670.89 ± 25.49[a]	842.97 ± 23.71[c]	772.06 ± 24.62[b]	871.13 ± 17.38[c]	0.000
Serosa	200.54 ± 8.25[a]	207.66 ± 16.50[a]	210.82 ± 14.98[a]	295.86 ± 14.28[b]	0.000

Values with different superscripts in a row differ significantly ($p<0.05$).

old and the minimal mucosal thickness was 122.82 µm in animals aged 1-4 years old. Previously, Abdel-Magied and Taha (2003) reported the average mucosal thickness of 200 µm in the non-glandular areas of the first compartment of the dromedary stomach.

In both nonglandular regions of C1, maximum thickness of the submucosa, inner circular and outer longitudinal smooth muscle layers and serosa were found in 12-16 years old animals and minimum thickness were found in 1-4 years old animals. The average thickness of the submucosa, muscularis and serosa in the first compartment of the dromedary stomach reported by Abuagla *et al* (2014) were 1124.16±521.41 µm, 1826.02±349.91 µm and 263.60±142.75 µm in the cranioventral glandular sac and 982.75±490.20 µm, 1788.90±817.44 µm and 143.90±67.9 µm in the caudodorsal glandular sac, respectively. Abdel-Magied and Taha (2003) reported mucosal thickness of the glandular sacs of the 1st compartment of the dromedary to be 250 µm.

In the present study, the mucosal layer was thicker in the cranioventral glandular sac in all groups, while the thickness of the other histological layers in the CVGS and CDGS varied among the studied groups. With the exception of the mucosal thickness, these results are consistent with those published by Abuagla *et al* (2014) who reported average mucosal thicknesses of 235.60±28.10 µm and 285.70±42.72 µm in the cranioventral and caudodorsal glandular sacs, respectively.

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References

Abdel-Magied EM and Taha AA (2003). Morphological, morphometric and histochemical characterisation of the gastric mucosa of the camel (*Camelus dromedarius*). Anatomia, Histologia, Embryologia 32:42-47.

Abuagla I, Ali H and Ibrahim Z (2014). Gross anatomical and histometric studies on the stomach glandular sacs of the dromedary camel (*Camelus dromedarius*). Sudan Journal of Science and Technology 15:46-56.

Allouch G (2016). Anatomical study of the water cells area in the dromedary camels rumen (*Camelus dromedarius*). Nova Journal of Medical and Biological Sciences 5(1)1-4.

Amasaki H, Gui R, Matsumoto S and Daigo M (1988). Scanning electron microscopic observation on the epithelial surface of the forestomach in bactrian camel, *Camelus bactrianus*. Japanese Journal of Zootechnical Science 59:527-531.

Banks WJ (1993). Applied Veterinary Histology 3rd Edn., Mosby Year Book. pp 338-349.

Chungath JJ, Radhakrishnan K, Ommer PA and Paily L (1985). Histological studies on caprine forestomach. Kerala Journal of Veterinary Science 16:41-46.

Czerkawski JM (1985). An Introduction to Rumen Studies. Oxford; Pergamon Press, Toronto.

Dougbag AS and Berg R (1980). Histological and histochemical studies on the mucosa of the initial dilated and middle long narrow part of the third compartment of the camel's stomach (*Camelus dromedarius*). Anatomia, Histologia, Embryologia 9:155-163.

Eerdunchaolu, Takehana K, Kobayashi A, Baiyin, Cao GF andren A, Iwasa K and Abe M (1999). Morphological characterisation of gland cells of the glandular sac area in the complex stomach of the bactrian camel (*Camelus bactrianus*). Anatomia, Histologia, Embryologia 28:183-191.

Eurell JA and Dellman H (1998). Textbook of Veterinary Histology. 5th Edn. Wiley. pp 155-195.

Franco A, Regodon S, Robina A and Redondo E (1992). Histomorphometric analysis of the rumen of sheep during development. American Journal of Veterinary Research 53:1209-1217.

Hansen A and Schmidt-Nielsen K (1957). On the stomach of the camel with special reference to the structure of its mucous membrane. Acta Anatomica 31:353-375.

Hegazi A (1950). The stomach of the camel. British Veterinary Journal 106:209-213.

Langer P (1988). The Mammalian Herbivore Stomach: Comparative Anatomy, Function and Evolution. Gustav Fischer Verlag.

Mathiesen SD, Haga E, Kaino T and Tyler NJC (2000). Diet composition, rumen papillation and maintenance of carcass mass in female Norwegian reindeer (*Rangifer tarandus tarandus*) in winter. Journal of Zoology 251:129-138.

Naghani ES and Akradi L (2011). Histogenesis of rumen in one-humped camel (*Camelus dromedarius*). Pakistan Veterinary Journal 32:269-272.

Osman EO (1999). Morphological and some immuno-histochemical observations on the stomach of the camel (*Camelus dromedarius*), Master of Science thesis, University of Khartoum.

Pérez W, König HE, Jerbi H and Clauss M (2016). Macroanatomical aspects of the gastrointestinal tract of the alpaca (*Vicugna pacos* Linnaeus, 1758) and dromedary (*Camelus dromedarius*). Vertebrate Zoology 66:419-425.

Poonia A, Kumar P and Kumar P (2011). Histomorphological studies on the rumen of the sheep (*Ovis aries*). Haryana Veterinarian 50:49-52.

Rabagliati DS (1924). The Dentition of the Camel. Cairo Govt. Press, Egypt. pp 1-32.

Sengar OPS and Singh SN (1970). Studies on the digestive system of ruminants. Part IV: Structure of the compound stomach in Buffalo. Agra University Journal of Research and Science 19:83-118.

Singh M, Nagpal SK and Singh Y (1996). Histomorphological studies on the glandular mucosa of rumen, reticulum and omasum in camels (*Camelus dromedarius*). Indian Journal of Animal Sciences 66:881-884.

Singh N, Puri JP, Nangia OP and Garg SL (1983). Early development of rumen function in buffalo calves. Rumen microbes, metabolism and cellulose digestion *in vitro* as a function of age and diet. Indian Journal of Animal Sciences 53:933-936.

Smuts MMS and Bezuidenhout AJ (1987). Anatomy of the Dromedary. Oxford University Press. pp 124-129.

Taluja JS and Saigal RP (1988). Postnatal histomorphological changes in subepithelial wall of buffalo rumen. Indian Journal of Animal Sciences 58:1161-1168.

Tamate H, Kikuchi T, Onodera A and Nagatani T (1971). Scanning electron microscopic observation on the surface structure of the bovine rumen mucosa. Archivum Histologicum Japonicum. Nippon Soshikigaku Kiroku 33:273-282.

Tiwari GP and Jamdar MN (1970). Studies of the gross and histological structure and development on the forestomach of indian water buffalo calf in early postnatal life with reference to normal feeding. II Reticulum. Indian Journal Animal Science 40:569-573.

Vallenas A, Cummings JF and Munnell JF (1971). A gross study of the compartmentalised stomach of two new-world camelids, the llama and guanaco. Journal of Morphology 134:399-423.

Vivo JM, Robina A, Regodon S, Guillen MT, Franco A and Mayoral AI (1990). Histogenetic evolution of bovine gastric compartments during the prenatal period. Histology and Histopathology 5:461-476.

Wang JL, Lan G, Wang GX, Li HY and Xie ZM (2000). Anatomical subdivisions of the stomach of the Bactrian camel (*Camelus bactrianus*). Journal of Morphology 245:161-167.