

MORPHOLOGICAL AND HISTOLOGICAL FEATURES OF THE STOMACH IN DOMESTIC PIGS (*SUS SCROFA DOMESTICA*)

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Abstract

Domestic pigs (*Sus scrofa domestica*) share significant anatomical and physiological resemblances with humans, making them an excellent animal model for studying the specific virulence mechanisms of pathogens, microbial pathogenesis, inflammatory response, and development of various microbial diseases. In recent years, the utilization of porcine models for studying human bacterial infections has increased, as a consequence of higher restrictions on the use of alternative animal models (non-human primates and dogs) for ethical reasons. The purpose of this study is to describe the morphological aspects and evaluate the histological variations in the different regions of the pig stomach to determine the morphological and histological similarities of the stomach in other monogastrics, including humans.

Sixty stomachs of the Landrace breed of pigs were collected immediately after slaughtering and examined to evaluate morphological and histological features. All examined pigs' stomachs exhibited the same morphological appearance: „C” shaped, hollow, muscular organ with two curvatures (lesser and greater). After opening along a significant curvature, the mucosal surface exhibited four different regions: an oesophageal region with pale color, greyish, a cardiac region, maroon colored, a fundic region, and a pyloric region with pinkish color, which ended with the pyloric sphincter. For histological examination, four samples of the gastric mucosa (*pars oesophagea*, *pars cardiaca*, *pars fundica*, and *pars pylorica*) were taken from each stomach, fixed in 10% neutral formalin, and embedded in paraffin wax, stained with hematoxylin and eosin, and assessed using the light microscope.

The oesophageal (non-glandular) region was covered with a non-keratinized stratified squamous epithelium, while all glandular regions (cardiac, fundic, and pyloric)

were lined with simple columnar epithelium. Gastric glands found in the fundic region were rich with parietal and chief cells, while mucous-secreting cells were most predominant in both cardiac and pyloric glands. In the non-glandular and glandular regions of pigs' stomachs, *tunica submucosa*, *tunica muscularis*, and *tunica serosa* have the same appearance. The *tunica submucosa* consists of connective tissue, collagen, elastic fibers, blood, and lymphatic vessels. The *tunica muscularis* contains sub-layers of smooth muscle cells mainly oriented in the longitudinal and circumferential direction of the organ, while the *tunica serosa* is made of loose connective tissue covered by a single layer of squamous epithelium called mesothelium.

In summary, regarding the similarities in size, shape, and function of stomach glandular regions in pigs and humans, pigs can serve as a useful animal model for various gastric-associated diseases.

Key words: Pigs stomach, Non-glandular, Glandular, Morphology, Histology.

1. Introduction

The stomach is a muscular, hollow organ located in the upper left abdomen as part of the gastrointestinal tract. Controlled by the autonomous nervous system, the stomach fulfills vital functions like storing, digesting, and propelling ingested food (Klemm *et al.*, [1]). Pigs are commonly used as a transnational model of gastrointestinal functions because they are similar in size and have anatomy and physiology comparable to humans (Gonzales *et al.*, [2]). Pigs have a relatively simple, single-chambered stomach, which is classified as monogastric. Morphological features of the pig's stomach revealed that it was a „C” shaped, muscular, hollow organ placed between the oesophagus and

duodenum, caudal to the diaphragm (Kadhim, [3]), with two curvatures, greater and lesser, and a conical blind sack called diverticulum (Dyce *et al.*, [4]). A pig's stomach is both structurally and functionally divided into four distinct regions: oesophageal, cardiac, fundic, and pyloric (Bauer *et al.*, [5]), in contrast to the human stomach, where the entire gastric lining is glandular (Krause *et al.*, [6], and Choi *et al.*, [7]). The only glandless part of the stomach is the oesophageal mucosa, which is located at the entrance of the oesophagus to the stomach and is a continuation of the oesophageal mucosa (Gandarillas and Bas, [8]). Every distinct glandular area of the stomach mucosa contains glands with characteristic cell types. Examination of the inner surface of the empty stomach shows numerous longitudinal folds or ridges referred to as rugae. Many openings, called gastric pits (foveolae), can be seen on the surface of the gastric mucosa. These invaginations form the openings for ducts into which the gastric glands empty (Klein, [9]). Histological studies of pig stomachs showed four layers: Tunica mucosa (lamina epithelialis, lamina propria, and lamina muscularis mucosae), submucosa, muscularis, and serosa. In recent years, the utilization of porcine models for studying human bacterial infections has increased, as a consequence of higher restrictions on the use of alternative animal models (non-human primates and dogs) for ethical reasons.

The purpose of this study is to describe the morphological aspects and evaluate the histological variations in the different regions of the pig stomach to determine the morphological and histological similarities of the stomach in other monogastrics, including humans.

2. Materials and Methods

2.1 Animals and tissue sampling

A total of 60 stomachs of the Landrace breed of pigs, 6-7 months old and weighing about 100 kg, were collected immediately after slaughtering. The stomachs were transported to the laboratory in an ice box (4 °C) and processed within 3 hours of collection. To study the inner morphological features of the pig's stomach, the stomach was excised along the significant curvature, from the diverticulum to the pylorus, the ingesta was removed, and the mucosal surface was gently washed. Both external and internal features were observed and recorded, along with figures.

2.2 Histological examination

For histological examination of the pig's stomach regions, biopsy samples were taken from the oesophageal, cardiac, fundic, and pyloric mucosa. Routinely, tissues are fixed in 10% neutral formalin, embedded in paraffin, and manually sectioned with

a microtome to obtain 5 µm-thick paraffin sections. All tissue sections were stained with hematoxylin and eosin and assessed using a light microscope.

3. Results and Discussion

3.1 Morphological features of the pig stomach

In the present investigation, the stomach of the domestic pig was a „C” shaped, unilocular, hollow organ with a smooth and homogenous external appearance, without any demarcation, placed between the oesophagus and duodenum. These findings were similar to those in the domestic pigs (Dyce *et al.*, [4]), dogs (Miller *et al.*, [10]), albino rats (Chandana *et al.*, [11]), and guinea pigs (Shrmean, [12]). To the left of the oesophagus, a blind sac was found, which itself possessed a diverticulum (Dyce *et al.*, [4], Eurell and Frappier [13], and Bal *et al.*, [14]). A similar result can be found in Babirusa pigs (Leus *et al.*, [15]). All pigs' stomachs revealed two curvatures: concave, lesser curvature, and convex, greater curvature (Trang *et al.*, [16]). The central part of the stomach was long in shape, while the terminal part was relatively short, cone-shaped, and led to the duodenum (Figure 1).

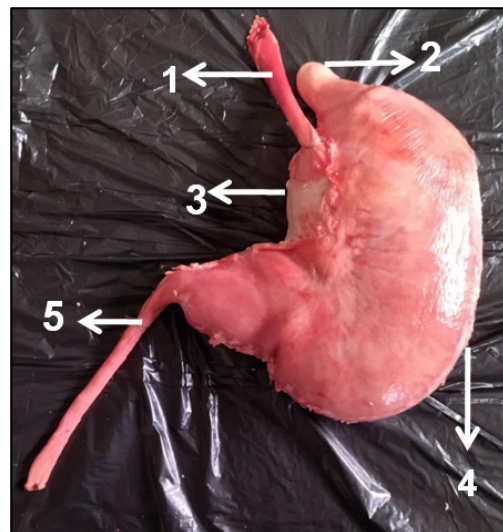


Figure 1. Gross anatomy of pig stomach: (1) oesophagus, (2) diverticulum, (3) lesser curvature, (4) greater curvature, (5) duodenum

After opening along a significant curvature, the inner mucosa showed four regions with different colorations: non-glandular (oesophageal), cardiac, fundic, and pyloric (Figure 2). The first region was the small non-glandular or oesophageal region, with a pale colour, located near the lesser curvature, while the second was a greyish cardiac region, circumscribed by a blind diverticulum. The third region was a maroon-coloured, fundic region with the presence of mucosal folding, followed by the fourth pyloric region with a pinkish colour, which ended with a pyloric sphincter (Erla *et al.*, [17]).



Figure 2. Functional regions of the pig stomach: (1) oesophageal region, (2) cardiac region, (3) fundic region, (4) pyloric region

3.2 Histological features of the pig stomach

Non-glandular region of the pig stomach starts with the first lamina of tunica mucosa, referred to as lamina epithelialis, presented by non-keratinized stratified squamous epithelium (Leus *et al.*, [15], and Langer, [18]) while lamina propiria comprised dense connective tissue and collagen fibers without the presence of any glands. The lamina muscularis mucosa is the outermost layer of the mucosa, composed of smooth muscle fibers (Figure 3).

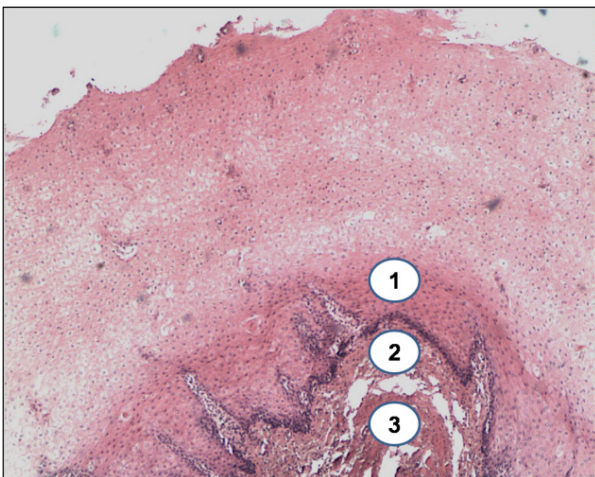


Figure 3. Oesophageal region: (1) lamina epithelialis, (2) lamina propiria, (3) lamina muscularis mucosae

The mucosal surface was covered with small depressions called gastric pits in all glandular regions (cardiac, fundic, and pyloric). The bottom of each is the orifices of the gastric glands. A single layer of columnar cells covers the mucous membrane surface and the surface of the stomach pits. The histological characteristics of functional gland regions appeared to be similar to those found in the Babyrousa pigs (Leus *et al.*, [15]), Moug Indigenous

and Vietnamese wild pigs (Trang *et al.*, [16]), and other mammals, including humans (Ross and Pawlina, [19]). In the cardiac region, the mucosal epithelium has rapidly transformed from stratified squamous in the non-glandular, oesophageal region to simple columnar that invaginates and creates the gastric crypts (Nitovski *et al.*, [20]). Tunica mucosa established short gastric pits (foveolae) containing openings to simple ducts of coiled, tubular mucous-producing cardiac glands in the lamina propria. Furthermore, lamina propria showed prominent aggregates of lymphoid tissue termed lymphoid follicles, which extended between cardiac glands (Figure 4). Lamina muscularis mucosa consisted of smooth muscle bundles.

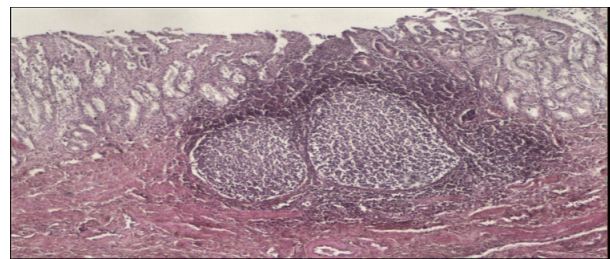


Figure 4. Presence of lymphoid follicles in the lamina propria of the cardiac region

In the fundic region of the pig stomach, tunica mucosa was darkly red colored, while the mucosal folds extended in different directions (Danacu *et al.*, [21]). Lamina propria was composed of loose connective tissue interspersed with smooth muscle and lymphoid cells, and within it were comprised simple, branched, tubular fundic glands that extend from the bottom of the gastric pits to the lamina muscularis mucosae. The gastric (or fundic) glands are straight, branched tubular glands composed of: mucous cells (in the neck), parietal cells (or oxyntic cells mainly in the neck, also in the base), chief cells (mainly in the base, also in the neck) (Figure 5) and scattered enteroendocrine cells (Amerongen, [22]).

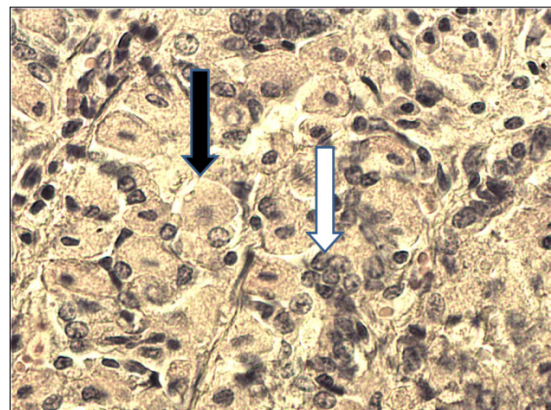


Figure 5. Proper gastric glands in the fundic region: parietal (large, triangular cells with eosinophilic cytoplasm, black arrow): chief cells (basophilic granular cytoplasm, white arrow)

The pyloric region was pinkish white, with a bulged torus pyloricus at the pyloric sphincter region. Moreover, these findings have been shown in pigs (Eurell and Frappier [13], Bal *et al.*, [14], and Laerke and Hedemann [23]), and rabbits (AL-Mahmodi, [24]). The short, tubular, branched pyloric glands were placed in the lamina propria (Figure 6). Thick strands of connective tissue that extended up from the base of the lamina propria mucosae divided the pyloric gland groups from one another.

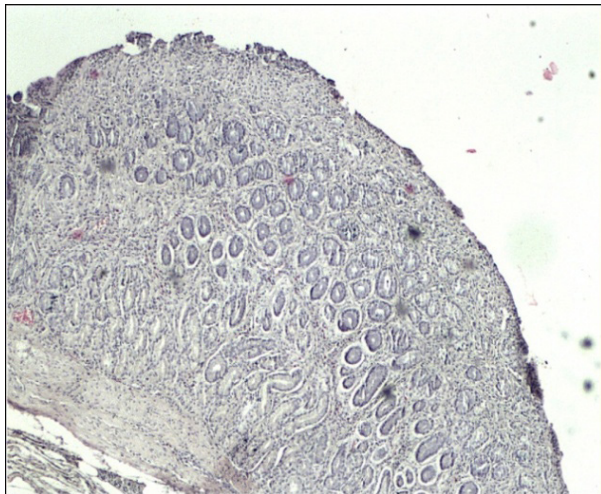


Figure 6. Pyloric tubular glands in the lamina propria

In the present study, the frequent appearance of lymphoid follicles in the lamina propria of the glandular region was found. The existence of lymphoid tissues in the gastrointestinal tract can be viewed as a genetically determined normal histological structure (Uhr, [25]). The study on gnotobiotic pigs showed that the lymph nodes in the submucosa of the cardiac region exhibited normal structure and could migrate to the mucosal layer (Driessen *et al.*, [26]).

In all regions of the pig stomach (non-glandular and glandular), despite their anatomical differences, tunica submucosa, tunica muscularis, and tunica serosa have the same appearance. The tunica submucosa consists of connective tissue, collagen, elastic fibers, blood, and lymphatic vessels. Tunica muscularis was presented with two (in non-glandular) or three layers (in glandular region) of smooth muscle: the innermost oblique, the middle circular, and the outermost longitudinal. The external surface of the stomach is covered by the tunica serosa. This thin layer consists of loose connective tissue covered by mesothelial cells (Ross and Pawlina, [19]).

4. Conclusions

- This study contributes to understanding the morphological and histological features of different regions of a pig's stomach and explains the exact

histological pattern of the gastric mucosa. Each region of the glandular part of the stomach contains secretory glands located in so-called gastric pits. All three types of gastric glands exhibit long, branched, tubular structures extending through the whole thickness of the lamina propria.

- Nonetheless, their cellular composition varies according to their location. Proper gastric glands in the fundic region are abundant in parietal and chief cells, while the mucous-secreting cells are predominant in cardiac and pyloric glands.

- Our findings emphasize the anatomical and histological similarities of pigs and humans' stomachs, therefore, pigs can serve as a useful animal model for various gastric-associated diseases.

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