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Anatomical, Histological, and Ultrasonographical Studies on the Liver of Red Fox (*Vulpes vulpes*) with its Arterial Blood Distribution and Biliary Ducts

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ABSTRACT

The study aimed to investigate the anatomical and histological characteristics of the Egyptian red fox. We performed liver ultrasonography on eight animals while used two livers for morphological study. To illustrate the hepatic artery branches, two specimens were injected with colored red latex neoprene through the abdominal aorta. The other two specimens were injected with a mixture of lead oxide and colored green latex neoprene through the major duodenal papilla to demonstrate the radiological images of the biliary duct pattern. The last two specimens were used for histological study. The fox's liver had six lobes; left lateral, left medial, quadrate, right medial, right lateral, and caudate lobes. The gall bladder was pear-shaped and was embedded in a fossa between the right medial and the quadrate lobes. The left hepatic duct formed the common bile duct, and the cystic duct union then passed about 0.5-1cm to join with the right hepatic duct. The branches of the proper hepatic artery supply the liver lobes. Histologically, liver parenchyma consisted of lobules; each lobule had a central vein and hepatic cords with hepatic sinusoids in between. Histochemically, hepatocytes were stained with Periodic Acid Schiff and Bests carmine stains. Gall bladder lined by simple columnar cells rests on fibrous propria-submucosa rich in blood capillaries. This study has practical importance in surgical treatment, as in partial hepatic lobectomy and hepatic artery or lobar arteries ligation in case of tumors.

Key words: Liver, Hepatic Artery, Bile Duct, Histology, Ultrasonography, Red Fox

INTRODUCTION

The red fox *(Vulpes vulpes)* is the most widely spread carnivore worldwide from the family of Canidae, which possess the great potential for adaptation due to its survival capability in different environments ranging from the arctic areas to the barren temperate deserts, and the heavily populated cities (Basuony et al. 2005). It is known as the most abundant carnivore in Egypt. The red fox *(Vulpes vulpes)* is present in most of North America, Europe, Asia, and part of North Africa (Hoffmann and Sillerozubiri 2021).

The gross anatomy of liver lobation, their scientific terms, as well as their vascular supply and biliary system are still the topic of research, in numerous species in rabbits (Reem et al. 2019; Al Hamdany 2019), n cat (Reem et al. 2019), in pig (Osman et al. 2008), and in dogs (Mari and Acocella 2015). The only description of the liver in the red fox was found by Cavallini (1997) mentioning the anatomical terms of the liver lobes and topographical anatomy.

The biliary system composed of the gall bladder, cystic duct, bile duct, and hepatic ducts with its intrahepatic distribution (Abd El-Hady 2002; Center 2009; Kook 2013). Liver disease is a common problem encountered in small animal practice. Many animals with liver disease manifest vague malaise, with variable clinical signs, such as icterus, ascites, coagulopathy, lethargy, anorexia, vomiting and diarrhea (Mannion 2006).

Ultrasonography evolved as an excellent diagnostic imaging tool for detecting liver and gall bladder alteration or abnormalities as common bile duct obstruction in cases of hepatic neoplasia and extrahepatic biliary obstruction in dogs, including pancreatitis, neoplasia, gallbladder mucoceles, cholangitis, and cholelithiasis or intrahepatic obstruction (Kealy 2010; Ellison 2011; Kumar et al. 2012). It is the diagnostic method of choice in veterinary fields to easily define the position of gall bladder (Kook

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2013). The echogenicity, size, contour of the liver, portal, and hepatic vein should be evaluated (Nyland et al. 2015; Griffin 2019). The vascular anatomy of the liver is significant for angiologists along with veterinary surgeons (El-Bably and Abouelela 2021).

Many studies focused on the liver morphology and its arterial supply in carnivores; however, such studies are scarce in the red fox (*Vulpes vulpes*). Thus, this study aimed to determine the anatomical characteristics of the liver in Egyptian red fox, filling the knowledge gap and supporting veterinarians with basic information on the anatomical and histological features as well as architecture and biliary system of the liver, which help in identifying the pathogenesis of the hepatic diseases with its sequential changes on the animal liver, thereby preventing tragic livestock loss.

MATERIALS AND METHODS

Ethical Approval of the Study

Our study was performed upon the approval of the international ethical standards set by the institutional animal care and use committee (Vet CU12/10/2021/365).

The present study was conducted on eight apparently healthy and fresh livers of adult red fox which were captured in steel traps by commercial fur trappers in Giza. The animals were housed under standard hygienic conditions with free access to food and water. The body weight (bwt) of fox and the weight of their livers were between 3-7kg and 400-800g, respectively. The eight animals were starved prior to the examination for 8h but drinking water was available then sedated by being injected intramuscular with Xylazine HCL (Xylaject 2%®, ADWIA, Egypt) in a dose of 1mg/kg bwt for applying the ultrasonography on liver. The examined foxes were euthanized by lethal dose of Diazepam at 10mg/kg intravenously through the external jugular vein.

The Ultrasonography examination

All eight live red foxes were manually restrained in the dorsal recumbent position at semi- dark room after sedation as mentioned before. The abdomen was clipped from the xiphoid cartilage of sternum caudally and also into the sides especially over the rib cage. Ultrasound coupling gel was applied. B-scan trans-abdominal ultrasound was done using a 5-10MHz linear transducer (Hitachi Aloka F31, Tokyo, Japan).

Based on our anatomical findings, the liver was scanned fully in both transverse and longitudinal sections by gently angling and moving the transducer from cranial to caudal and from right to left. The cranial aspect of the liver adjacent to the diaphragm must be examined and the caudal tips of the liver lobes also seen. The gall bladder and the porta hepatis are useful landmarks. Scanning of the liver was at the 11th–12th intercostal space dorsally as this ensures visualization of aorta, then caudal vena cava and portal vein.

A. Anatomical study

Two liver specimens were used for studying the topographical position and morphological studies. An abdominal incision was made to expose the abdominal viscera clearly. Topographical localization of liver was done by removal of intercostal muscles to show the liver position, lobes, ligaments and morphology of the gall bladder. The liver was extracted and dissected fresh from each animal, washed with normal saline solution (0.9%) and photographed then fixed in 10% formalin solution for 24h.

Two specimens were injected with colored red latex neoprene through the abdominal aorta for investigating the branches of hepatic artery and then preserved in 10% formalin about 24-48h before the routine dissection. Last two specimens were injected with the mixture of lead oxide and colored green latex neoprene through the major duodenal papilla for demonstrating the radiological images of biliary ducts immediately by using the radiographic apparatus (Fisher imaging, Chicago, USA)

All results were documented by taking several photographs. The anatomical nomenclatures presented in this work were in conformity with the *Nomina Anatomica Veterinaria* 2017 (6th Ed).

Histological study

Sample collection and preparation

Portions of right and left lobes of two livers were removed rapidly and fixed in 10% neutral buffered formalin for 48h. The fixed samples were dehydrated in an ascending series of alcohol cleared in xylene, and embedded in paraffin wax overnight, and then 4-5um paraffin sections were obtained by a rotatory microtome.

For light microscopic examination

Specimens were stained by Hematoxylin and Eosin (H&E) stain for histological structure (Bancroft and Gamble 2013).

Histochemical Examination

Hepatic sections were stained with periodic acid Schiff (PAS) stain for the detection of neutral mucopolysaccharides, and Best's Carmine stain for glycogen (Bancroft and Gamble 2013).

RESULTS

Normal Ultrasonography Features of the Red Fox's liver

The liver contour of red fox was smooth and regular, delineated by a thin hyperechoic capsule. The liver had six lobes, namely, left lateral (LLL), left medial (LML), quadrate (Q), right medial (RML), right lateral (RLL), and caudate lobes (C). The left lobes were displayed on the right of the ultrasonographic examiner and the right lobes on the left. The gall bladder was an oval-shaped anechoic organ with a hyperechoic thin wall. It was located between the right medial and the quadrate lobes. The right kidney was caudally visible in contact with the caudate lobe of the liver. The size of the gall bladder was variable, which increased in fasted foxes. The intrahepatic biliary tree was not visible.

The landmarks for liver detection included porta hepatis, portal vein, hepatic vein, and gall bladder. The hepatic veins had fewer echogenic walls unlike the portal vein, which had more echogenic walls (Fig. 1A, B).

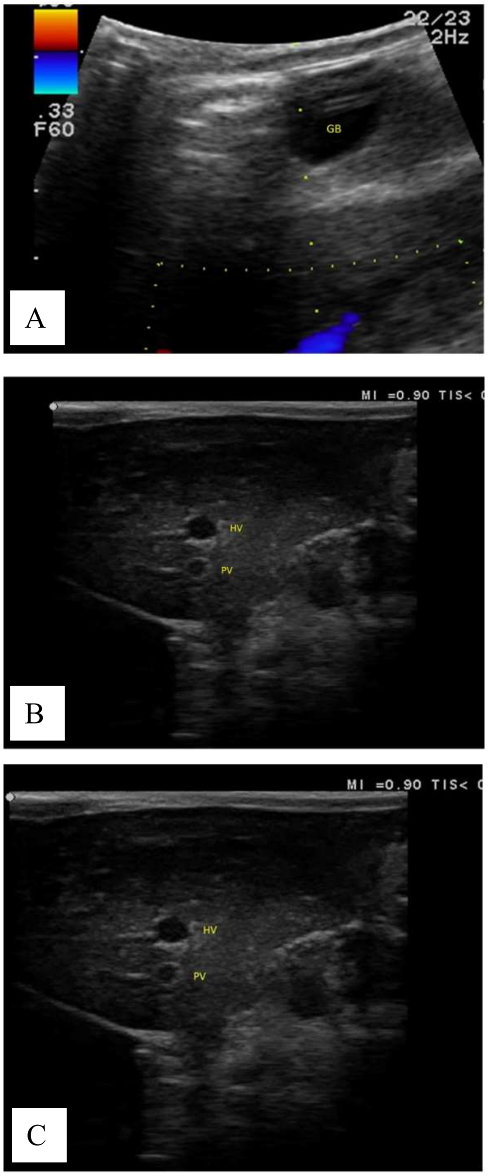

Fig. 1: A: The liver parenchyma is coarsened appearance to a quite fine-grained texture, gall bladder wall has fine echogenic line and anechoic content. B: The longitudinal section of hepatic, portal vein and caudal vena cava which hepatic vein has less echogenic wall than portal vein which run to the periphery of the lobes. C: Cross section of hepatic and portal vein.

The liver appearance was compared with the spleen, and the right kidney. The liver was more hyperechogenic than the spleen with a diffuse, slightly coarse-grained texture (Fig. 2). The liver was isoechoic compared to the right kidney (Fig. 3).

Topographical and morphological anatomy of the Red Fox's liver:

The present study revealed that the liver of the red fox (Fig. 4) was weighed average 400–800gm and had a dark brownish color in the fresh soft state. It was placed just caudal to diaphragm centrally in the abdominal cavity. It extended from the left side of the abdomen from the 8th to the 13th rib related to surrounding organs; stomach, jejunum and dorsal end of the spleen. While

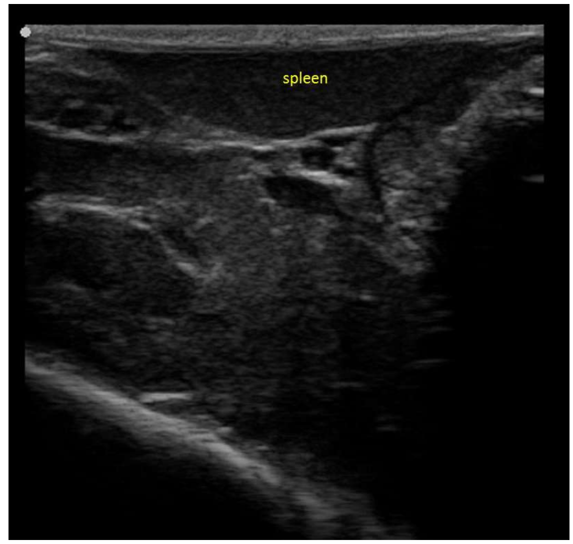

Fig 2: The liver is more hyperechogenic than the spleen with a diffuse, slightly coarse-grained texture.

Fig 3: The liver is isoechoic with the right kidney.

from the right side, the liver was situated in relation with descending duodenum, jejunum, and right kidney, extended from the 9th to the 13th rib.

The liver had two surfaces, namely, a strongly convex parietal surface was dome shape, facing cranially the diaphragm, and a deep concave visceral surface, facing caudally and had gastric, intestinal, and renal impressions. The visceral liver surface had a depression called the porta hepatis that lay dorsal to the small impression of the pyloric part of the stomach.

The liver of the red fox was divided into six lobes, converged at the portal fissure, and separated from each other by very deep interlobar fissures. The liver lobation was as follows: LLL, LML, Q, RML, RLL, and C (Fig. 4, 5, 7B)

The lobus hepatis sinister was the largest and divided into LLL and LML (Fig. 4, 5, 7B). The LLL was the largest lobe, oval in shape, and partially covered the small LML. It was found resting on the ventral abdominal floor, in the left half of the abdominal cavity. The entire visceral surface of the left lobe showed gastric impression except for a small ventral area for jejunal impression.

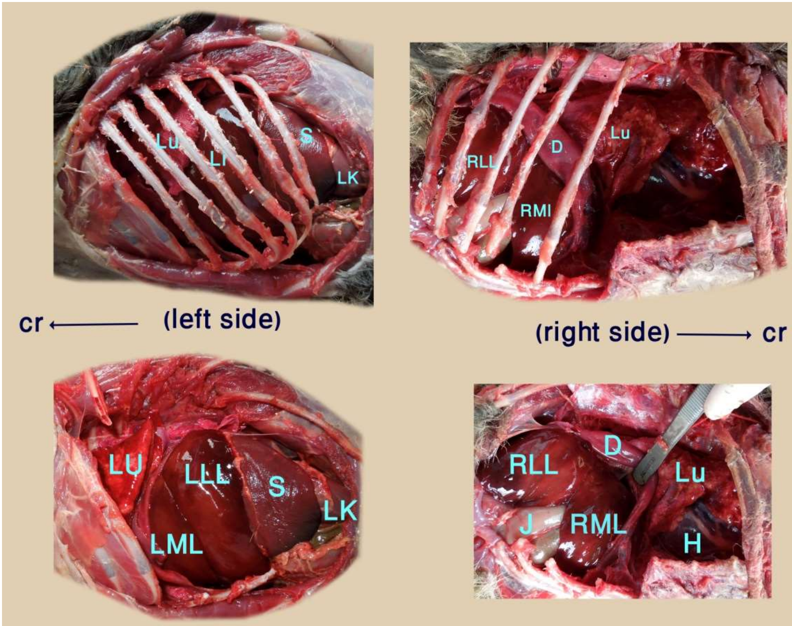

Fig 4: The topographical anatomy of liver in red fox.

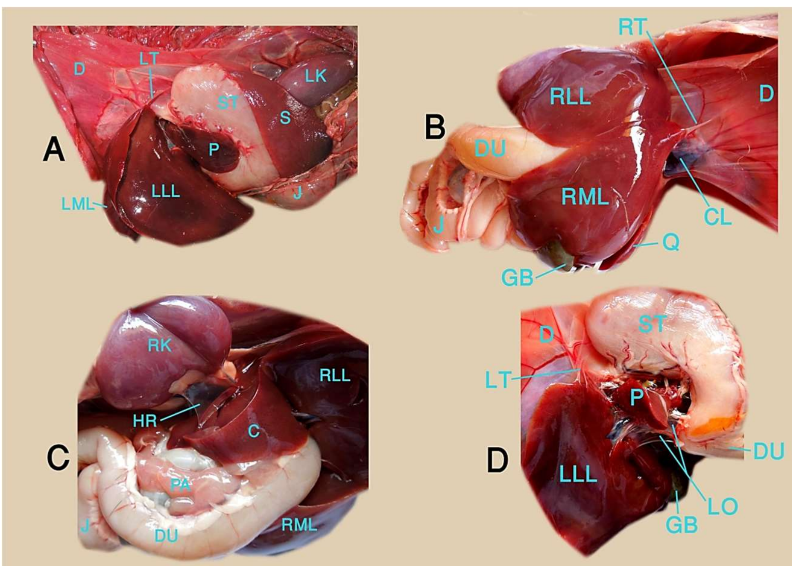

Fig 5: The ligaments of liver in red fox.

Legends for Fig. (4-5)

C: *Processus caudatus*; *Lobus caudatus*, p: *Processus papillaris; Lobus caudatus*, RLL: *Lobus hepaticus dexter lateralis*, RML: *Lobus hepaticus dexter medialis*, Q: *Lobus quadratus*, LML: *Lobus hepaticus sinister medialis*, LLL: *Lobus hepaticus sinister lateralis*, GB: *Vesica fellea*, D: Diaphragm, LU: Lung, Li: Liver, S:Spleen, H: Heart, J: Jejunum, LK: Left kidney, RK: Right kidney, ST: Stomach, DU: duodenum, PA: Pancreas, LT: Left triangular ligament, RT: Right triangular ligament, CL: *Lig.coronarium hepatis*, LO: Lesser omentum, HR: *Lig.hepatorenale*.

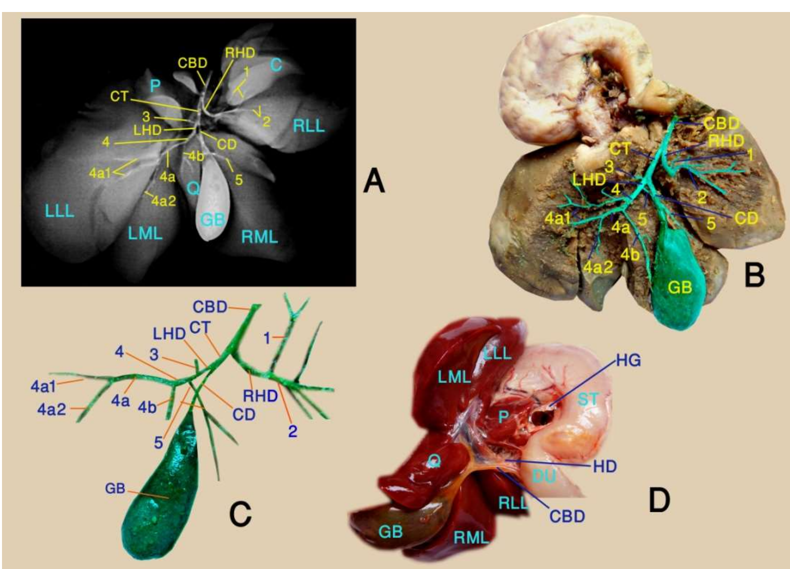

Fig 6: The Visceral surface of liver of fox showing gall bladder, cystic duct.

Legends for Fig. 6:

CBD: *Ductus Choledochus*, CD: *Ductus cysticus*, RHD: *Ductus hepaticus dexter*, LHD: *Ductus hepaticus sinister*, HG: *Lig. Hepatogastricum*, HD: *Lig. hepatoduodenale*.

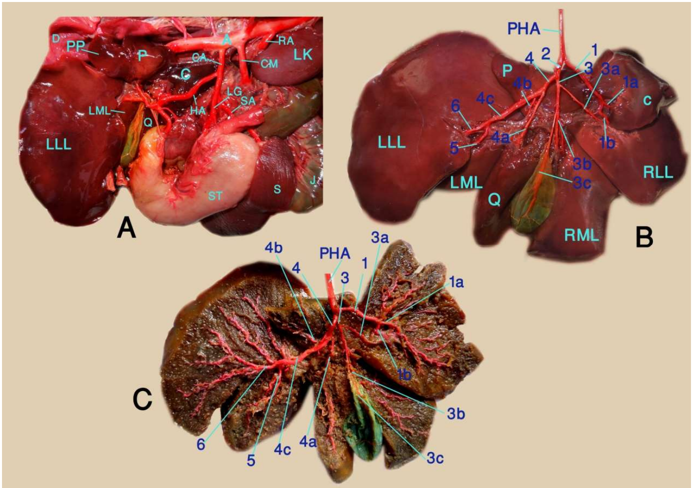

Fig 7: The intrahepatic arteries of fox liver.
Legends for Fig. 7:
HA: *A. hepatica* PHA: *A. hepatica propria* 1. *Ramus dexter lateralis* 2, 4. *Ramus sinister* 3. *Ramus dexter medialis* 5. *Ramus sinister medialis* 6. *Ramus sinister lateralis*.

The lobus quadrates was small slender tongue-shaped, and separated from the left medial lobe by a deep umbilical fissure and from the right medial lobe by the gall bladder (Fig. 5, 7B/Q). It was situated in the midline of the abdomen.

The lobus hepatis dexter was located in the right half of the abdominal cavity. It was separated into RML and RLL (Fig. 4, 5, 7B) by a deep interlobar fissure. The RML was larger than RLL. The RLL carried the C lobe on the dorsal part of its visceral surface. The parietal surface of RLL partially covered the visceral surface of the RML.

The lobus caudatus (Fig. 5, 7B/C) was situated on dorsal part on the visceral surface of RLL. It was divided into two segments; the papillary process directed to the left and the caudate process facing to the right. The caudate process (processus caudatus) (Fig. 5C/C) showed deep renal impression for the right kidney. The papillary process (processus papillaris) (Fig. 5A/P) was loosely covered by the lesser omentum.

The liver was fixed in its position by the pressure of the surrounding organs and peritoneal attachments. The peritoneal attachments of the liver were as follows: lesser omentum (Fig. 5D/LO), which consisted of two parts, the hepatogastric ligament (Fig. 6D/HG) attached to the lesser curvature of the stomach with a visceral surface of the liver and the hepatoduodenal ligament (Fig. 6D/HD) connected between the first part of the duodenum and visceral surface of the liver. The hepatorenal ligament (Fig. 5C/HR) was situated between the right kidney and the caudate lobe. The right and left triangular ligaments (Fig. 5/LT, RT) were attached to the dorsal border of the right lateral or left lateral lobes with the diaphragm, respectively). Well-developed coronary ligaments (Fig. 5B/CL) attached the liver to the diaphragm.

Gall bladder and biliary system:

The gall bladder (vesica fellea) (Fig. 6/GB) was a pear-shaped sac embedded in a fossa *(fossa vesicae felleae)* between the RML and the Q making impression on both lobes. It exceeded the ventral border of the liver and can be seen from both liver surfaces. Within the liver, canaliculi drained bile into interlobular ducts. These converged further into lobar ducts that became known as *hepatic ducts* as they exited the liver parenchyma and formed part of the extrahepatic biliary tract.

Ductus choledocus

The common bile duct (Fig. 6/CBD) was created by the union of the left hepatic and cystic ducts and then passed approximately 0.5–1cm to join with the right hepatic duct. It is located at the porta hepatis, ventral to the portal vein entrance, and lies in the hepatoduodenal ligament then separately opened into the duodenum on major duodenal papilla approximately 1–2 cm caudal of the pylorus.

I- Ductus cysticus

The cystic duct (Fig. 6/CD) was a long straight duct extended from the neck of the gall bladder, 2cm long. During its course, it joined with the left hepatic duct forming a common trunk (Fig. 6/CT) then fused with the right hepatic duct.

II- Ductus hepaticus dexter

The right hepatic duct (Fig. 6 /RHD) was a small slender duct formed by the union of several radicals which drained the bile from the C lobe and RLL (Fig. 6/1,2, respectively). The duct was joined to a common trunk that was formed by the cystic and left hepatic duct union.

III- Ductus hepaticus sinister

The left hepatic duct (Fig. 6/LHD) drained bile from the LLL, LML, Q, the papillary process of the C, and the RML. It was formed by union of radicles drained from the LLL and LM by 4–5 small intrahepatic ducts (Fig.6 /4a1,4a2). Along its course, it received duct from papillary process (Fig. 6/3) and another duct collected from the Q via 2–3 branches (Fig. 6/4b) and thin long duct drained the RML (Fig. 6/5).

Arterial blood supply of the liver:

The main nutritional blood supply of the liver was derived from the hepatic artery (*A. hepatica*) (Fig. 7A/HA). This artery arose from the celiac artery, which was the first branch of the abdominal aorta after this later artery pierced the aortic hiatus of the diaphragm. The hepatic artery was the longest branch of the celiac artery that supplied the liver, pancreas, the first part of the duodenum, the pyloric part, and the greater curvature of the stomach.

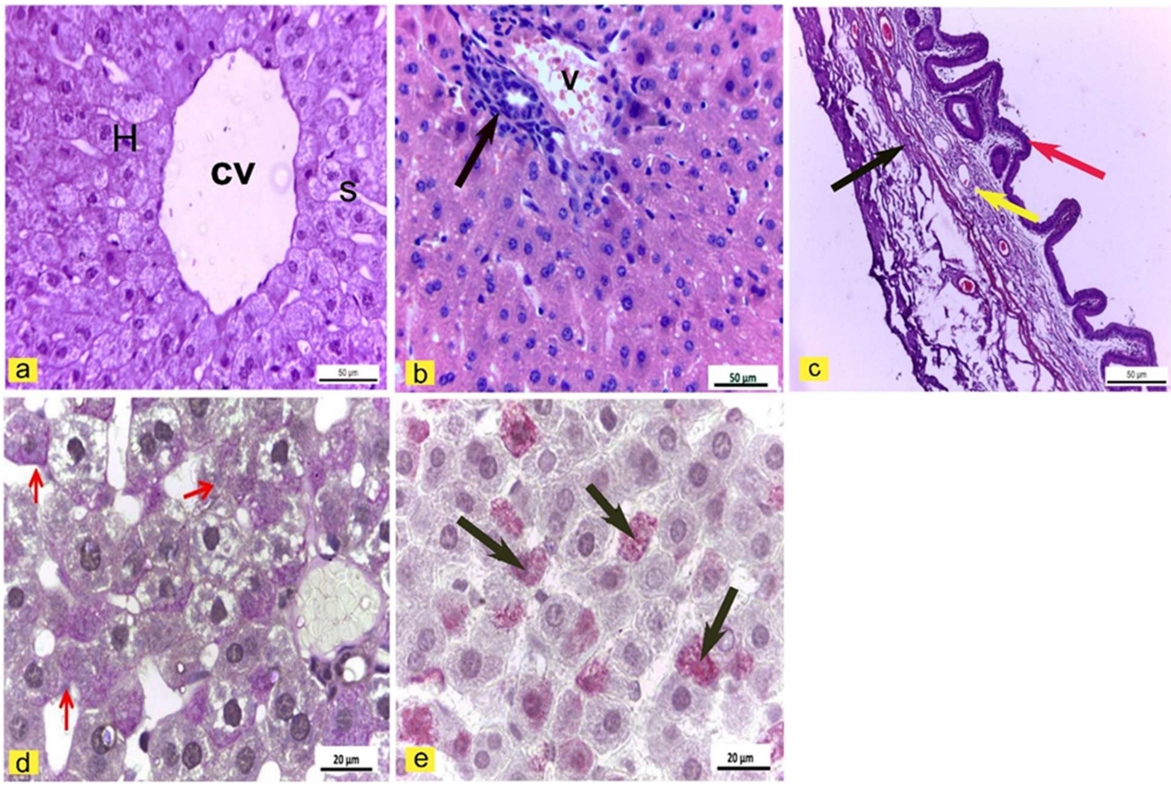

Fig. 8a & b) Liver sections of red fox. H&E stain X400. **a)** Hepatic parenchyma composed of central vein (CV), hepatic cords (H) and hepatic sinusoids (S). **b)** Normal portal area had branch of portal vein (v) and branch of interlobular bile duct (arrow). **c)** Gall bladder of red fox lined by simple columnar absorptive cells (red arrow) rest on fibrous propria-submucosa rich in blood capillaries (yellow arrow) and tunica musculosa formed of circular smooth muscle fibers run in different directions (black arrow). **d)** Positive reactivity of hepatocytes to PAS stain. PAS stain X1000. **e)** Positive reactivity of hepatocytes to Bests carmine stain. Bests carmine stain X1000.

A. Hepatica Propria **(Fig. 7B, C/PHA)**

Only one proper hepatic artery (PHA) supplied the liver of the red fox. It bifurcated into the right lateral and left branches that penetrated the different hepatic lobes.

R. dexter lateralis **(Fig. 7/1) of PHA** was detached as long slender artery that supplied both the RLL and caudate process of the C (Fig. 7/1a, 1b). This artery released three branches, two fine branches to the caudate process *(Aa. lobi caudati)* while one branch to right lateral lobe arborized into six fine twigs.

R. sinister (Fig. 7/2) was larger than the right lateral one. It was divided into two branches. The first, right medial branch *(R. dexter medialis)* (Fig. 7/3), gave off four branches as follows: a long slender branch to the RLL, two branches for the RML, and a cystic artery (*A. cystica*) (Fig. 7/3a, 3b, 3c) to supply the gall bladder and bile duct. The second branch of the *R. sinister*, continuation of the R. sinister, (Fig. 7/4) was trifurcated to release three branches; one to the Q (Fig. 7/4a), another small twig to the papillary process of the C (Fig. 7/4b) that ramified into three fine intrahepatic branches. The third-largest branch (Fig. 7/4c) supplied the left lobe. This later branch was divided into *R. sinister medialis* and *lateralis* for the LML and LLL, respectively (Fig. 7/5, 6). The *R. sinister medialis* ramified into two rami supplying the LML, while the *R. sinister lateralis* detached four rami for the LLL. The arrangement of the hepatic artery branches according to appearance.

I. Histological investigation

I. Light microscopic observations:

H&E-stained sections of the fox liver revealed normal histological architecture composed of hepatic lobules, each lobule consisted of hepatocytes arranged in cords that radiated from the central vein and separated by anastomosing hepatic sinusoids. Hepatocytes were polygonal in shape and had one or sometimes two spherical nuclei (Fig. 8a). Hepatic sinusoids are lined by endothelial cells and von Kupffer cells. A normal portal triad was present between the hepatic lobules that contain branches of the portal vein, hepatic artery, and an interlobular bile duct (Fig. 8b).

The gall bladder of the red fox was lined by simple absorptive columnar epithelium resting on propria-submucosa that formed fibrous connective tissue rich in blood capillaries. The tunica muscularies are composed of circular smooth muscle fibers that run in different directions (Fig. 8c). The free part of the gall bladder is covered by tunica serosa but the attached part with the liver is covered by tunica adventitia.

b- Histochemical observations

Histochemically, hepatocytes displayed positive reactivity to Periodic Acid Schiff (PAS) (Fig. 8d) and Bests carmine stains (Fig. 8e).

DISCUSSION

Anatomical and ultrasonographical studies

The scarcity in the research about hepatic lobation, arterial supply and biliary system in the red fox encouraged us to present the first illustrated detailed study on the macroscopic anatomy, topography and arterial distribution and bile tracts of the red fox.

The liver topography results of the present study agreed with those described in the liver of cats, rabbits, guinea pigs and domestic animals (Dyce et al. 2010; Stan 2018; Reem et al. 2019) that it was situated entirely in the abdominal cavity, just caudal to the diaphragm, extending from the left side of the abdomen from the 8th to the 13th rib and lies on the right side from the 9th to the 13th rib.

According to the present study, the liver lobation of the red fox appeared to be divided into six lobes as follows: LLL, LML, QL, RML, RLL, and CL. This was in resemblance to that described by Breton (2008) and Osman et al. (2008) in dogs, cats, and pigs and also in resemblance to Nomina Anatomica Veterinaria (2017). However, Al Hamdany (2019), Reem et al. (2019) and Stan (2018) found the lobation to be five lobes, in case of rabbits, due to the undivided right lobe, while Tammam et al. (2017) found the same previous result because of the undivided the left lobe in rats.

Concerning the liver ultrasonography, the left lateral approach to image the gall bladder of the liver is unnecessary, unlike deep-chested dogs. This difference may be contributed to the small size of the red foxes. The gall bladder is increased in fasted foxes as post-prandially enzymes are released, which cause the gall bladder to contract. The intrahepatic biliary tree is not visible in foxes similar to dogs in contrary with cats (Mannion 2006)

The liver is more hyperechogenic than spleen of the red fox unlike deep chested dogs as their spleen is more hyperechogenic than liver (Nyland et al. 2015). Compared with the right kidney of the red fox, the liver is isoechoic similar to deep chested dogs as their kidney may be hypoechogenic or isoechoic with liver (Nyland et al. 2015). Therefore, comparison of the liver echogenicity with spleen is more reliable than with kidney.

Regarding the present study, the following six ligaments fixed the liver in its position: the hepatogastric, hepatoduodenal, hepatorenal, right triangular, left triangular, and coronary ligaments, which was similar to the result mentioned before by De Iuliis and Pulerà (2007) in cats and Dyce et al. (2010) in domestic animals.

No former literatures described the arterial and biliary duct system in the red fox's liver; thus, the present study gave the detailed information about arterial distribution, biliary system, and their variations that were of a major significance for experimental hepatobiliary surgery and hepatic transplantation (Sänger et al. 2015).

The gall bladder was a pear-shaped sac embedded in a fossa between the RML and Q making impression on both lobes as well as reported by Dyce et al. (2010) in dogs and Stamatova et al. (2012) and Stan (2018) in rabbits. It exceeded the ventral margin of the liver and appeared from both surfaces of the liver as in dogs (Piérard 1996; Dyce et al. 2010) but disagreement with Reem et al. (2019) in rabbits and cats, which reported that the gall bladder appeared only viscerally and did not reach the ventral hepatic margin.

Our observation revealed that the presence of a common bile duct in red foxes was similar to the findings of Osman et al. (2008) in pigs, but Brockman (2013) and Reem et al. (2019) reported the absence of common hepatic duct in dogs, cats and rabbits. Moreover, the formation of the common bile duct in the present study was the union of the left hepatic and cystic ducts then passed approximately 0.5–1 cm to join with the right hepatic duct. Such results were in agreement with Reem et al. (2019) in rabbits. However, contrary to our investigation, in buffalo, Abd El-Hady (2002) reported that the cystic duct joined the right hepatic duct then converged with the left hepatic duct forming the common bile duct. Reem et al. (2019) revealed the formation of this duct in cats by the union of the left, right hepatic, and cystic ducts. Brockman (2013) described that the lobar hepatic ducts open separately from the cystic duct in canines.

Concerning the intrahepatic bile tract distribution, the present work revealed that the left hepatic duct drained bile from the LLL, LML, Q, the papillary process of the C, and RML. Such results were in agreement with Abd El-Hady (2002) in buffalo and Stamatova et al. (2012) and Stan et al. (2018) in rabbits. Meanwhile, the right hepatic duct created by the union of several radicals which received the bile from the C lobe and RLL as mentioned by Abd El-Hady (2002) in buffalos, Dyce et al. (2010) in dogs, and Reem et al. (2019) in cats and rabbits.

The course and number of hepatic arteries were diversely great, which may account for different descriptions in the literature. Previous studies (Evans 1993; Nickel et al. 1996; NAV, 2017) stated that three hepatic artery branches entered the liver (*ramus dexter lateralis, ramus dexter medialis,* and *ramus sinister*), while in some other literatures, 3–5 hepatic branches (Evans 1993), 1–3 (Niza et al. 2004), 1–5 (Evans and de Lahunta 2004) were recorded.

Our result reported that the liver of red foxes is supplied by a single PHA in all cases. In resemblance to the current findings in the red fox, Ursic et al. (2006) in dog, Osman et al. (2008) in pig and Stamatova et al. (2018) in rabbit clarified that right lateral, right medial, and left branches were the main arteries that supplied the liver. Additionally, Ursic et al. (2006) described that in dogs, the first and smaller right lateral (*Ramus dexter lateralis*) and the second and larger left branches (*Ramus sinister*) were the main branches emitted from the hepatic artery, which was following our observations in all cases of the red fox.

Concerning the *R. dexter medialis*, the present study agreed with Ursic et al. (2006) that it detached from the left branch and is supplied by the RML. Ursic et al. (2006) explained that, in some cases, the right medial branch originated immediately from the hepatic artery and fine twigs for the RML, Q, and gallbladder.

Ursic et al. (2006) in dogs pointed out the presence of an artery supplying the caudate process that emitted straight from the hepatic artery termed *Ramus processus caudate*, yet in our observations, the caudate process vascularized by two branches derived from the right lateral branch of the hepatic artery similar to the results mentioned by Osman et al. (2008) in pigs and Stamatova et al. (2018) in rabbits.

Noticeably, the literature reported that some hepatic lobes received dual sources of vascularization. Our work on the red fox revealed that the only part of the liver that received double arterial supply was the RLL, derived from both the right lateral and right medial branches, in agreement with Ursic et al. (2006).

Moreover, Evans (1993) in dogs mentioned that the LML and Q were supplied by both the left and the right medial branches, which differs from our results that showed the LLL, LML, and Q were vascularized by fine rami from the left branch of PHA, as well as recorded by Vdoviaková (2016) in rats and Stamatova et al. (2018) in rabbits.

The gall bladder artery in the current work in the red fox and Ursic et al. (2006) in dogs reported the detachment of the *A. cystica* from the *R. dexter medialis*. Contrary to the NAV (2017), it was released from *R. sinister medialis*. Additionally, the vascularization of the papillary process of the C was illustrated in the liver of the red fox from an artery that arose as a solitary branch of the *R. sinister*, the same as described by Ursic et al. (2006) in dogs.

Finally, both *R. sinister medialis* and *R. sinister lateralis* were noticed as the terminal ramification of the *R. sinister* to the LML and LLL, as observed in our findings and by Ursic et al. (2006).

Histological study

The current investigation revealed that the liver of the red fox consisted of hepatic lobules, each lobule had a central vein and hepatic cords with hepatic sinusoids in between. Hepatocytes are polygonal in shape with one or two spherical and central nuclei. Hepatic sinusoids are lined by endothelial cells and von Kupffer cells. These findings come in line with the reports of Choudhury and Singh (2013) in prenatal sheep, Singh et al. (2014) in a fetus of buffalo, and Thakur et al. (2019) in buffalo. A Portal triad was present between the hepatic lobules that contain branches of the portal vein, hepatic artery, and an interlobular bile duct. This result agrees with Dellmann (1993) and Thakur et al. (2019). The gall bladder of the red fox was lined by simple absorptive columnar epithelium resting on propria-submucosa that formed fibrous connective tissue rich in blood capillaries. The muscular layer is composed of circular smooth muscle fibers that run in different directions. This finding correlates with MacPherson et al. (1984) who reported the muscle layer of the canine gall bladder wall was a three-dimensional meshwork of smooth muscle bundles, which appear loosely and irregularly arranged.

Histochemically, hepatocytes displayed positive reactivity to PAS and Bests carmine stains. This indicates that hepatocytes of the red fox's liver contain neutral mucopolysaccharides and glycogen granules. This result comes in contact with Thakur (2020) who stated that hepatocytes showed an intense reaction to PAS stain in buffalo liver.

Conclusion

The morphological study of the liver, it's vascular and hepatobiliary systems of the red fox resembled that of other carnivores. Moreover, this study highlighted significant variation that might be related to the accommodation to natural habitat and type of diet between the red fox and other animals. Additionally, our study recorded the double arterial vascularization in some liver lobes of fox with practical importance in the clinical veterinarian in surgical treatment as in partial hepatic lobectomy and hepatic artery or lobar arteries ligation in case of tumors.

Author's contribution

NA Shaker, MH Hassan, IA Emam, YH Ahmed and SM El Gammal designed the protocol and collected the samples. HA Ahmed worked for histological slides. MH Hassan, and IA Emam performed Doppler and ultrasonographical images. NA Shaker and SM El Gammal performed the anatomical and topographical of fox liver and its biliary system and vascular architecture. All authors drafted the manuscript, reviewed, and approved the last version of the manuscript.

Conflict of interest

There are no conflicts of interest to declare.

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