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Anatomical distribution of the hepatic artery in sheep

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Abstract
The present study was conducted in twenty two apparently healthy sheep irrespective of sex. Dissection, corrostion casting and radio-opaque techniques have been applied to show the different ramifications of the hepatic artery vascular branching pattern with its topographic relations in sheep. The results revealed that the common hepatic artery originated from the coeliac artery, which was divided into right and left hepatic arteries at hilus. The right hepatic artery further divided into common trunk, caudate process artery and cystic artery. The common trunk gave rise to right superior and inferior interlobular arterys which were mainly supplied blood to superior, inferior region of right lobe. The right central interlobular artery originated along with right inferior interlobular artery which was supplied blood to diaphragmatic region of right lobe. The caudate process of the caudate lobe and gall bladder was mainly supplied by the caudate process artery and cystic artery respectively. The left hepatic artery was subdivided into left medial and lateral branches. The left medial branch gave rise to the left superior and intermediate inter lobular arterys, which was supplied to superior and intermediate region of the left lobe respectively. The left lateral branch gave rise to quadrate lobe artery and left inferior inter lobular artery which was supplied to various regions of quadrate lobe and left inferior region of the left lobe respectively.

Keywords: Sheep, liver, hepatic artery, vascular branching pattern.

Introduction
The liver is the largest gland that performs various functions essential for the life. The liver morphology is functionally divided into lobes characterized by their blood and bile distribution. The dual blood supply of the liver was a unique feature and it receives a generous blood supply through the hepatic artery and portal vein. Hepatic artery is branch of coeliac artery which is itself a branch of abdominal aorta (Getty 1975, Nickel, Schummer and Seiferli 1979). The vascular distribution of hepatic artery is related to the liver lobes (Azevedo *et at*. 2008; Bianchi *et al*. 2015). The three-dimensional vessel arrangement which was great importance for analysing the anatomical variations of the vascular anatomy within the organ (Schmidt *et al*. 1980) this was practical importance in liver surgery because dissection planes and incisions depend to a great extent upon vessel anatomy (Niza *et al*. 2004). Howeve, the sheep vascular system (hepatic artery, portal vein, bile duct) and macroscopic shape of liver are anatomically similar to humans and the surgical experience with sheep liver closely resemblance to the human organ, it holds a great potential for creating an ideal animal model (Teh *et al*. 2007 and Budai *et al*. 2017). Perhaps, it could be providing a better approach to interdisciplinary approach between Veterinary and the Human medical research purposes. It is noticed from the literature reviewed that there is very little information available in this front. This has prompted to take up this study to establish a more precise and detailed information on the structure of hepatic artery and vascular branching pattern with its topographic relations which would give a comprehensive and useful data for interdisciplinary works.

Materials and methods
Gross dissection
The hepatic artery was dissected by fixing the liver in 10% NBF to enable the study of course and branching.

Corrosion casting
The liver samples along with coeliac artery were collected from nine apparently healthy sheep irrespective of sex from local slaughter houses. After isolation of liver along with blood vessels, the right gastric and gastroduodenal artery was ligated cranial to the liver. The hepatic artery was cannulated and the arterial system was flushed with lukewarm heparinized saline solution. Cold cure self-polymerizing acrylic (methyl methacrylate) solution was reconstructed in 1:2 ratio with few drops of red color dye. This solution was injected into the hepatic artery ensuring the flow towards the gravity. The vessels were clamped and the injected liver

specimens were kept at room temperature for effective polymerization. Subsequently the specimens were digested in 75% hydrochloric acid till the corrosion process was completed. The specimen was cleaned under running water to remove macerated tissue leaving the vesselsexposed. The obtained cast was immersed in a solution made of equal quantity of formalin and glycerin to make it fungal free and to give the caste an extra shine.

Morbid arteriography

The branching pattern of hepatic artery in sheep was also studied by employing morbid arteriography. Specimen was prepared on similar procedural lines used for corrosion caste method. The radio-opaque suspension was prepared by dissolving red lead oxide @ 20 mg/100 ml of soap solution and was injected through hepatic artery under steady and constant digital pressure with help of cannula and syringe while keeping the specimen towards gravity. The injected liver was radio graphed immediately at 10 MAS, 42 KVP and 70cm FFD in different profiles to study the hepatic arterial branching pattern.

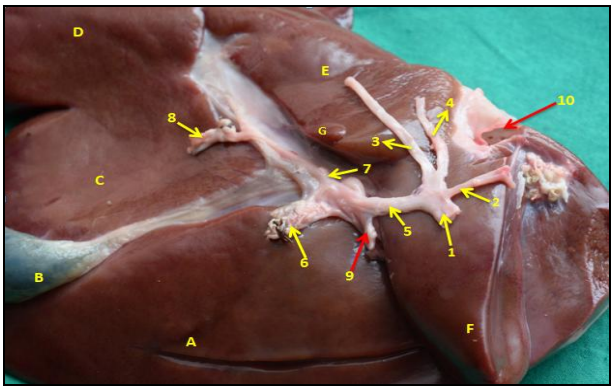

Fig 1: Photograph showing the common hepatic artery origin (visceral view).

A. Right lobe, B. Gall bladder, C. Quadrate lobe, D. Left lobe, E. Caudate lobe, F. Caudate process of caudate lobe, G. Papillary process of caudate lobe.
1. Coeliac artery 2. Splenic artery 3. Left gastric artery 4. Left ruminal artery 5. Common hepatic artery 6. Gastroduodenal artery 7. Proper hepatic artery 8. Right gastric artery 9. Portal vein 10. Posterior venacava.

Fig 2: Photograph of Acrylic cast showing the parenchymal distribution of the hepatic artery.

Common hepatic artery (CHA), Gastroduodenal artery (GDA), Proper hepatic artery (PHA), Right hepatic artery (RHA), Left hepatic artery (LHA), Right superior interlobular artery (RSILA), Rright inferior interlobular artery (RInfILA), Right central interlobular artery (RCILA), Caudate process artery (CPA) Cystic artery (CA), Left medial branch (LMB), Lateral branches (LLB), Left superior inter lobular artery (LSILA), Left intermediate inter lobular artery (LIILA), Quadrate lobe artery (QLA), Left inferior inter lobular artery (LInfILA).

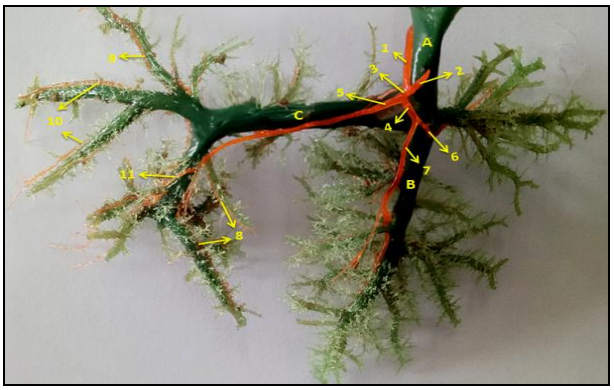

Fig 3: Photograph of Acrylic cast showing CHA divided into RHA and LHA (red coloured) in relation to portal vein (Green coloured).

A. Common portal vein. B. Right portal vein. C. Left portal vein.
1. CHA 2. GDA 3. PHA 4. RHA 5. LHA 6. CPA 7. CA 8. QLA 9. LSILA 10. LIILA 11. LInfILA.

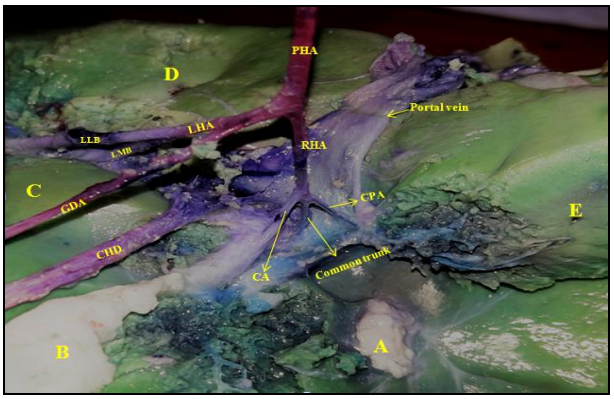

Fig 4: Photograph showing the extrahepatic divistions of hepatic artery.

A. Right lobe B. Gall bladder C. Quadrate lobe D. Caudate lobe E. Caudate process.

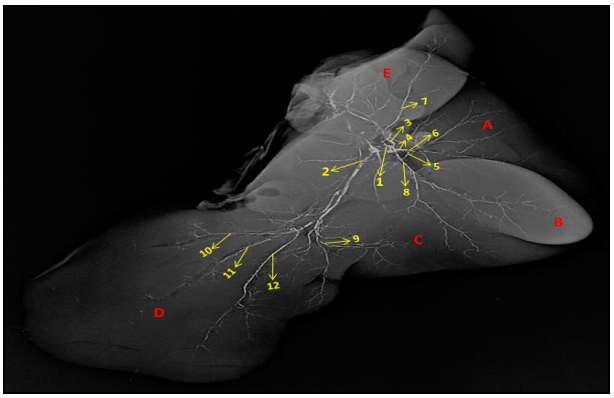

Fig 5: Morbid arteriogram showing the various divistions of RHA and LHA.

A. Right lobe, B. Gall bladder, C. Quadrate lobe, D. Left lobe, E.Caudate process of caudate lobe.

1. RHA 2.LHA 3. RSILA 4. Commontrunk 5. RCILA 6. RInfILA 7. CPA 8. CA 9. QLA 10. LSILA 11. LIILA 12. LInfILA.

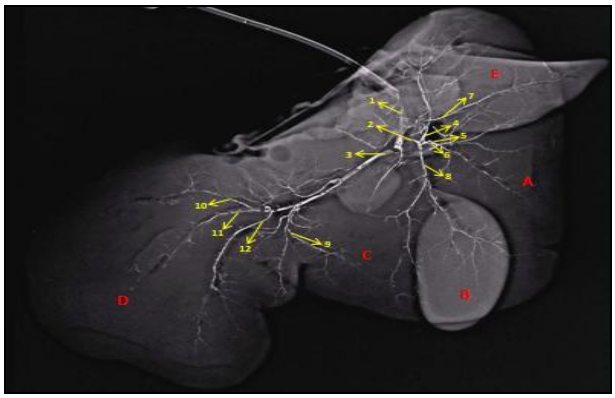

Fig 6: Morbid arteriogram showing branches of RHA & LHA, Specifically the origin of RSILA (rare case).

A. Right lobe, B. Gall bladder, C. Quadrate lobe, D. Left lobe, E. Caudate process of caudate lobe.
1. CHA. 2. RHA. 3. LHA. 4. RSILA. 5. RCILA. 6. RInfILA. 7. CPA. 8. CA. 9. QLA. 10. LSILA. 11. LIILA. 12. LInfILA.

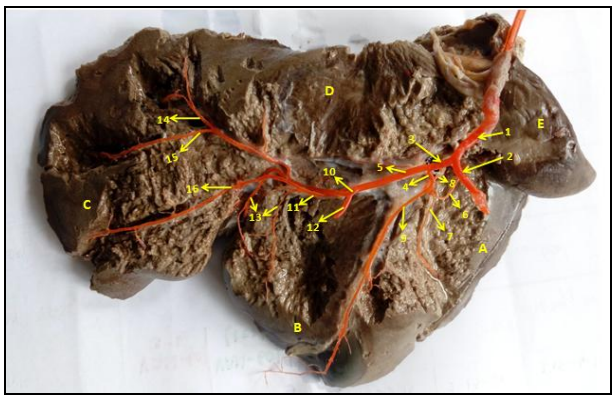

Fig 7: Photograph of Acrylic cast showing the parenchymal distribution of RHA & LHA (visceral view).

A. Right lobe, B. Quadrate lobe, C. Left lobe, D. Caudate lobe, E. Caudate process of caudate lobe.
1. CHA 2. GDA 3. PHA 4. RHA 5. LHA 6. RSILA 7. RInfILA 8. CPA 9. CA 10. LMB 11. LLB 12. RGA 13. QLA 14. LSILA 15. LIILA 16. LInfILA.

Fig 8: Photograph showing cystic artery bifurcastion & distribution.

A. Neck of the gallbladder. B. Body of the gallbladder. C. Fundus of the gall bladder.

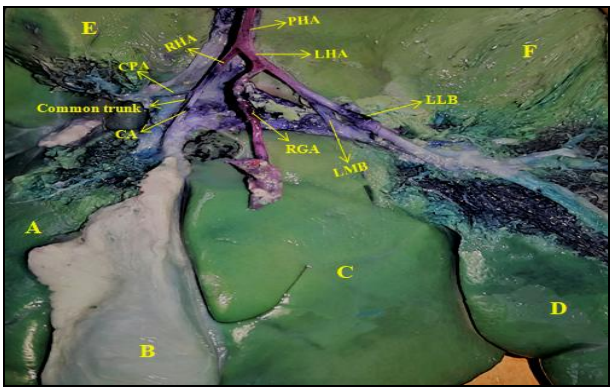

Fig 9: Photograph showing the LHA relesing RGA before dividing into LMB & LLB.

A. Right lobe, B. Gall bladder, C. Quadrate lobe, D. Left lobe, E Caudate process. F. Caudate lobe.

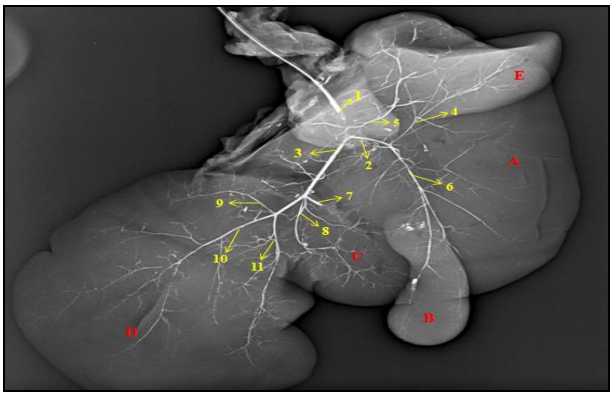

Fig 10: Morbid Arteriogram showing divistions and branches of CHA, RHA and LHA.

A. Right lobe, B. Gall bladder, C. Quadrate lobe, D. Left lobe, E.Caudate process of caudate lobe.
1. CHA 2. RHA 3. LHA 4. CPA 5. RSILA 6. CA 7. RGA 8. QLA 9. LSILA 10. LIILA 11. LInfILA.

Results

The common hepatic artery originated from the right side of the celiac artery along with the splenic and left gastric arteries. It preceded cranioventrally crossing posterior venacava and gave the gastroduodenal artery and continued as proper hepatic artery (Fig. 1 & 2). The proper hepatic artery divided into right hepatic artery and left hepatic artery at hilus.

The coursing pattern of RHA and LHA followed the branching pattern and course of the portal vein (Fig. 3). The right lobe of the liver was mainly supplied by right hepatic artery, whose branches were common trunk, caudate process artery and cystic artery. The common trunk gave rise to right superior and inferior interlobular artery. The right superior interlobular artery ascended obliquely to ramify in the superior region of the right lobe and continued dorsolaterally for about 3-4 cm giving branches mainly to superior region of the right lobe while small branches to caudate process of caudate lobe (Fig. 2 & 5). However, in a few cases it directly originated from the right hepatic artery (Fig. 6). The right inferior interlobular artery extended ventrally forming a curve along its course towards the ventral border of the medial part of the right lobe and gave 3 to 4 branches which ran in different directions supplying blood to these regions (Fig. 5 & 7). The right central interlobular artery originated along with right inferior interlobular artery. It had a horizontal course and

distributed to the diaphragmatic region of the right lobe and papillary process (Fig. 2, 5 & 6). The caudate process artery arose directly from the right hepatic artery in all animals studied. It supplied blood to the caudate process of the caudate lobe (Fig. 2, 6 & 7). The cystic artery gave small branches to the duct and lateral part of the right lobe and quadrate lobe (Fig. 5, 6, 7). At the neck of the gall bladder it divided into two or three branches which supplied blood to the free margin, right and left margins of gall bladder (Fig. 8).
The left hepatic artery extended from the hilus to the junction between left and quadrate lobes. It gave branches to papillary process of caudate lobe. Then the right gastric artery was given before it was sub divided into left medial and lateral branches which ran parallel with in the liver (Fig. 9). Left medial branch gave rise to the left superior inter lobular artery and left intermediate inter lobular artery, which was supplied to superior region and intermediate regions of the left lobe respectively (Fig. 2 & 7). The left lateral branch gave rise to quadrate lobe artery which supplied to various regions of quadrate lobe and further gave rise to left inferior inter lobular arterywhich supplied to inferior region of the left lobe (Fig. 2, 5, 6, 7 & 10).

Discussion

The common hepatic artery originated from the celiac artery Similar to the observations reported by Nickel *et al*. (1979) in domestic mammals, Seo *et al*. (2001) in rabbit, Anuradha *et al*. (2002) in buffalo calves, Alsafy, (2009) in goat, Dyce *et al*. (2010) in ruminants and other domestic animals, Oliveira *et al*., (2012) in prey, Bianchi *et al*. (2015) in rabbit, Kamath, (2015) in human cadavers, Das and Appaji, (2016) in human cadavers, Kuru (2016) in rabbit, Mohamed *et al*. (2016) in sheep, Mohamed *et al*. (2017) in goat and Thamke and Rani, (2017) in human cadavers.
The common hepatic artery in the present study gave the gastroduodenal artery and continued as proper hepatic artery. This finding is in accordance with Seo *et al*. (2001) in rabbit, Shirai *et al*. (2005) in cow and oxen, Oliveira *et al*. (2012) in prey, Tam *et al*. (2014) in rabbit, Mohamed *et al*. (2016) in sheep, Mohamed *et al*. (2017) in goat and Thamke and Rani, (2017) in human cadavers where they reported that the proper hepatic artery was part of the common hepatic artery and it gave the gastrodudeonal artery.
The proper hepatic artery divided into right hepatic artery and left hepatic artery. These findings are in full agreement with the observations of Nickel *et al*. (1979) in domestic animals, Anuradha *et al*. (2002) in buffalo calves, Shirai *et al*. (2005) in cow and oxen, Teh *et al*. (2007) in sheep, Souza *et al*. (2007) in capybara, Azevedo *et al*. (2008) in agouti, Osman *et al*. (2008) in pigs, Silva *et al*. (2014) in armadillo, Tam *et al*. (2014) in rabbit, Kamath, (2015) in human cadavers, Das and Appaji, (2016) in human cadavers, Kuru, (2016) in rabbit, Mohamed *et al*. (2016) in sheep, Vdoviakova *et al*. (2016) in rat, Mohamed *et al*. (2017) in goat and Thamke and Rani, (2017) in human cadavers where they reported that the proper hepatic artery divided into right and left hepatic artery. The current findings of proper hepatic artery dividing into right and left hepatic artery in sheep was contra to the observations of Ursic *et al*. (2007) in dog, Alsafy, (2009) in goat and Oliveira *et al*. (2012) in prey where they observed that proper hepatic artery gave three hepatic artery branches before entery into the hilus of the liver.
The caudate process artery in the present study arose directly from the right hepatic artery in all animals under study. It supplied blood to the caudate process of the caudate lobe. The present findings are in full acceptance with the observations of Osman *et al*. (2008) in pigs, Alsafy (2009) in goat, Oliveira *et al*. (2012) in prey, Silva *et al*. (2014) in armadillo and Vdoviakova *et al*. (2016) in rats where they reported that the caudate lobe artery originated from the right hepatic artery but contrary to the reportings of Seo *et al*. (2001) where it was reported in rabbits that proper hepatic artery gave rise to caudate lobe artery supplying to caudate lobe of the liver.
Cystic artery in the present study was the branch of right hepatic artery this finding is in consonance with the observations of Anuradha *et al*. (2002) in buffalo calves, Teh *et al*. (2007) in sheep and Thamke and Rani, (2017) in human cadavers, where they mentioned that this artery was branch of right hepatic artery. However, Kuru, (2016) in rabbit reported that the left hepatic branch gave the cystic artery to the gall bladder in humans.
The LHA in the present study extended from the hilus to the junction between left and quadrate lobes before it was sub divided into left medial (LMB) and lateral branches (LLB) which ran parallelly with in the liver. It gave branches to papillary process of caudate lobe. Then the right gastric artery was given. Such detailed course and branching of the LHA was not noticed in the literature reviewed so far. However, the observation like the LHA giving origin to the RGA was reported by Alsafy (2009) in goats, Kuru (2016) in rabbits, Mohamed *et al*. (2016) in sheep and Mohamed *et al*. (2017) in goats.
In the context of the left lateral branch (LLB) in the current study, it gave rise to QLA which supplied to various regions of quadrate lobe and further LLB gave rise to left inferior inter lobular artery (LInfILA) which supplied to inferior region of the left lobe. Whether it is for LMB or LLB no information was available in the literature reviewed. Few of the authors like Osman *et al*. (2008) in pigs, Alsafy (2009) in goats and Silva *et al*. (2014) rabbits reported that the QLA directly branched from LHA instead of LLB as observed in the present studies.

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