ISSN: 1220-3173; E-ISSN: 2457-7618

THE SURGICAL ANATOMY OF THE SWINE LIVER - A NEW WAY OF LEARNING FOR RESIDENTS IN TRAINING -

ANATOMIA CHIRURGICALĂ A FICATULUI SUIN - O NOUĂ METODĂ DE STUDIU PENTRU MEDICII REZIDENȚI -

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ABSTRACT | **REZUMAT**

The current information regarding the surgical anatomy of the swine liver is insufficient for the development of a consistent protocol of training in hepatic resection surgery, using the pig as the experimental model. The aim of our study is to expand the current knowledge about the surgical anatomy of the swine's liver for residents in training. We performed ex-vivo dissection on 40 livers, obtained from pigs weighing between 110 and 120 kg, and in-vivo dissection of 12 pigs, during an experimental training program in swine liver surgery. Before every surgery we organized an ex-vivo dissection phase and during live surgery face-to-face discussion sessions, in which the residents reported any surgical relevant anatomical feature by comparing it with human anatomy.

Our study confirmed part of the existing information about the liver like the relation with the diaphragm, the highly anatomical variability of the branches of hepatic artery, the presence of the glissonian pedicle, intraparenchymatous trajectory of the inferior vena cava and disagreed with other - the 3 hepatic vein pattern. Also we described new anatomical features: the high fragility of the hepatic capsule in the area where the ligaments enter the liver, the absence of triangular ligaments and bare area found in humans, the three distinct parts of the portal vein and the special relations between the vena cava and liver parenchyma. The anatomy of the swine liver is similar to that of the human liver, however there are some particularities. For residents in training a practical way to learn swine liver surgical anatomy can be the "face to face" model, an easy comparing system with the human anatomy.

Keywords: swine liver, surgical anatomy, training, residents

Nivelul actual de informații cu privire la anatomia chirurgicală a ficatului suin se dovedește a fi insuficient pentru a permite elaborarea unui protocol de învățare și perfecționare în chirurgia rezecțională hepatică, folosind porcul drept model experimental.

Prezentul studiu are scopul de a extinde nivelul actual de cunoștințe cu privire la anatomia chirurgicală a ficatului suin, în vederea folosirii informației pentru instruirea medicilor rezidenți.

A fost efectuată disecția ex-vivo a 40 de ficați prelevați de la porci cu masa corporală între 110 și 120 kg și disecția in-vivo a 12 porci, în cadrul unui program experimental de instruire în chirurgia hepatică.

Fiecare intervenție, a fost precedată de disecția ex-vivo a unui ficat suin, iar în timpul intervențiilor au fost realizate sesiuni de discuție, în care rezidenții au raportat particularitățile anatomice cu relevanță chirurgicală precum și elemente importante de anatomie comparate cu anatomia omului, identificate în cursul operației.

Prezentul studiu este în concordanță parțială cu datele existente în literatura de specialitate, confirmând informațiile despre raporturile ficatului cu diafragmul, variabilitatea ramurilor arterei hepatice, prezența pediculului glissonian, traiectul intraparenchimatos al venei cave inferioare, contrazicând informații legate de drenajul venos al ficatului (modelul cu 3 vene hepatice). Am identificat particularități de anatomie chirurgicală precum fragilitatea ridicată a capsulei hepatice la nivelul zonelor unde ligamentele se inseră pe organ, absența ligamentului triunghiular și a ariei nude întâlnite la om, posibilitatea de a împărți vena portă, în funcție de traiectoria pe care o descrie, în 3 regiuni distincte și raporturile deosebite pe care le are vena cavă inferioară cu parenchimul hepatic. Anatomia ficatului suin este similară cu cea a ficatului uman, având însă o serie de particularități.

Pentru medicii rezidenți aflați în perioada de formare modelul de învățare comparativ cu anatomia umană de tip "face-to-face" poate reprezenta o modalitate practică și usoară de însușire a cunoștințelor de anatomie chirurgicala a ficatului.

Cuvinte cheie: ficat suin, anatomie chirurgicală, instruire, rezidenți

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Modern liver surgery is based on a thorough knowledge of the liver's anatomy (2). Considering that the anatomical structure of the pig and human liver is similar, pigs can be used in training process of the medical residents, in order to obtain basic knowledge of surgical technique and tactic (5, 6). The current data regarding the surgical anatomy of the pig liver are not sufficiently detailed and systematized in order to be used for the training of the surgery residents (5, 6, 9). Due to the complex structure of the liver and its multiple relationships with the surrounding organs, liver surgery on pigs and implicitly collecting in vivo data on organ anatomy are difficult tasks(3). However, if we refer to the swine ex-vivo anatomy, difficulties arise in recognizing the intrahepatic structure, the organ segmentation, its exact anatomical position, relations and the trajectory of the nearby structures (ligaments, blood vessels, bile ducts etc.).

Given the aforementioned, the anatomical similarity in matter of color, texture and elasticity between the human and pig liver, the ease with which a pig can be acquired and its liver immediately harvested, thus preserving the structure of the organ, we consider it necessary to study both in-vivo and ex-vivo anatomy of the porcine liver starting with the macroscopic analysis of the ex-vivo organ.

In order to learn the relationships of the liver with the other intraperitoneal organs and its connections with the blood vessels and biliary tract, in-vivo liver study is required. In this situation, even with the help of the knowledge gained from ex vivo dissections, it is necessary to use a considerable number of pigs (variable) to study the surgical anatomy liver in detail.

Thus, there is a difficulty in the learning process generated on the one hand by the number of animals used (concomitant with the other related problems: legal, administrative and financial), and on the other by the time required to acquire this knowledge.

To overcome the drawbacks mentioned above we introduced a new approach to the learning process. Thus, the data obtained from numerous training activities (for the elaboration and implementation of a protocol regarding laparoscopic hepatic resections in pigs) of the resident doctors were corroborated and compared with the similar human structures (1, 8) in the "face to face" manner: we analysed the similarities and differences between common anatomical structures and clarifications were made where particular anatomical data were of surgical importance.

The present study is focused on the surgical anatomy of the liver in order to be further used in an integrated training program for residents in surgery. Starting from these data, studies can be made that will solve the problems of surgical technique and tactics starting from an anatomical-surgical knowledge base dedicated to this type of surgery.

MATERIALS AND METHODS

In order to obtain a correct and complete image on the anatomy of the pig liver, we used both in vivo and ex vivo organ dissections. For the ex-vivo dissection we obtained pigs from slaughterhouses in the vicinity of Cluj-Napoca. The pigs were slaughtered, respecting the current laws and regulations by the personnel of the slaughterhouse. The process was supervised by a team of veterinary and general surgeons that collected the livers of the pigs and brought them to the laboratory for the dissection (Fig. 1). We collected 40 livers from subjects weighing between 110 and 120 kg. All organs were dissected according to the same protocol: starting with the means of attachment, then the elements of the hepatic pedicle, the hepatic veins and inferior vena cava (IVC) and finally the dissection of the parenchyma. All the dissections were performed by mixed teams of veterinary and general surgeons.

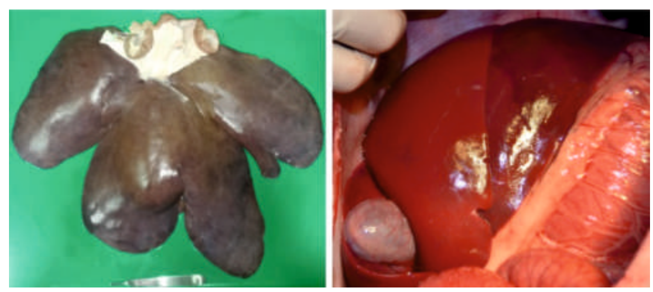

Fig. 1. Swine liver before dissection (left - ex vivo, right - in vivo)

For the in-vivo anatomy of the liver we used data collected during a training program in laparoscopic liver research. This program started in 2016 and spanned for three years, during which general surgery residents in surgery performed, under the supervision of experienced surgeons, liver resection on pigs. A total of 12 pigs, both male and female (weighing between 30 and 40 kg) were anesthetized and subsequently operated during the program (Fig. 1).

During each performed surgery, we organized face-to-face debriefing sessions, in which we asked the residents about the anatomical features observed during the surgery, thus obtaining precious data about the in-vivo and surgical anatomy of the swine liver. We mention that all the surgeries were approved by the ethical committee of our center.

RESULTS AND DISCUSSIONS

The liver is anatomically divided into three distinct lobes: the median lobe (subdivided into the left and right paramedian lobes), the left hepatic lobe, the right hepatic lobe that contains the IVC and the parenchyma adjacent to it forms the caudate lobe; both the caudate and square lobes are visible only on the visceral face of the liver. The fissures that delimit the anatomical lobes are deeper (and thus easier to recognize) than in humans. The umbilical fissure (median) divides the liver into two (right and left hemilivers) and also the median lobe into two paramedian lobes, incompletely divided posteriorly. It contains the round ligament and its insertion at the level of the portal vein. The other two fissures, right and left, divide the paramedian lobes from the proper left and right ones (Fig. 2).

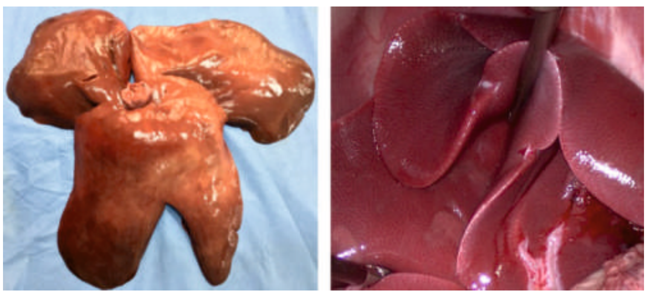

Fig. 2. Liver fissures
(left - ex vivo, right - in vivo, laparoscopy)

Attachments and ligaments. By macroscopically analysing the ex-vivo liver we noticed that the entire organ is covered by two peritoneal sheets (one superior /cranial and one inferior/caudal), that leave no free area such as the bare area (*aria nuda hepatis*), present in the human liver.

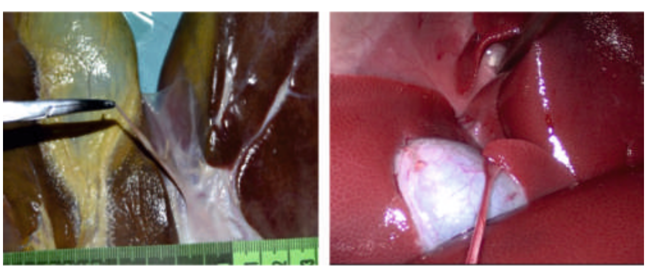

Fig. 3. The round ligament
(left - ex vivo, right - in vivo, laparoscopy)

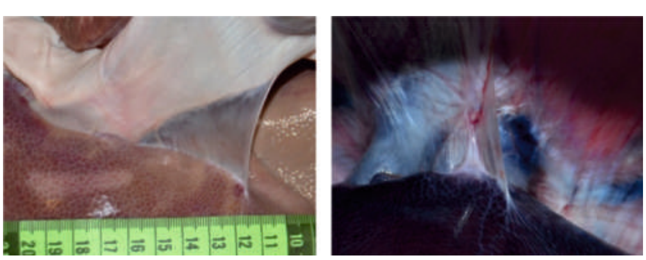

Fig. 4. The falciform ligament
(left - ex vivo, right - in vivo)

At a closer examination we were able to observe the following structures: the round ligament (more exactly a part of it) as an elastic cord, with a diameter between 2 and 3 mm, that enters in the umbilical groove (Fig. 3), the falciform ligament as a thin but traction-resistant membrane (less developed as in humans, it does not reach the anterior margin of the liver) (Fig. 4), the coronary ligament formed by the junction of the peritoneal sheets that cover the liver on both sides of the falciform ligament, anchoring the liver on the diaphragm (Fig. 5). We identified no equivalent structure to the triangular ligaments, thus we consider to have no equivalent in pigs.

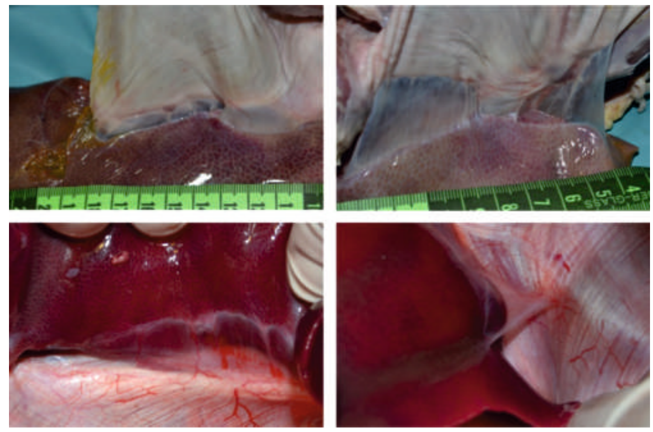

Fig. 5. The coronary ligament
(upper part - ex vivo, lower part - in vivo)

The in vivo analysis revealed the existence of a free, 2-3 mm diameter cylindrical structure, which links the abdominal wall to the liver - equivalent of the round ligament (Fig. 1), a peritoneal structure that connects the diaphragm to the liver capsule, equivalent to the falciform ligament (Fig. 3), and the coronary ligaments. We mention that during the laparoscopic intervention the subject was placed in the dorsal decubitus, a position that does not allow complete visualization of the right side of the coronary ligament. The ligaments that connect the diaphragm with the liver surround the area where the IVC emerges from the hepatic parenchyma (as we will describe later, in pigs the IVC has an intrahepatic portion), forming a common ligament-vein-diaphragm structure, that increases the difficulty of dissection at this level due to the very difficult control of the bleeding and the increased risk of producing the lesions to major vascular structure (Fig. 6).

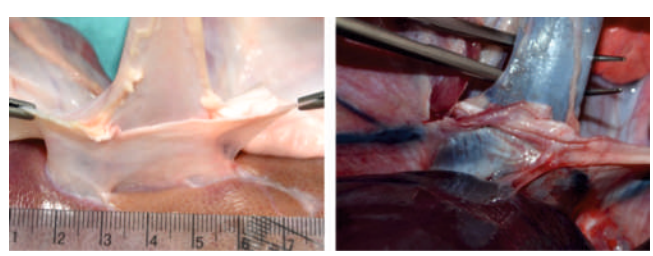

Fig. 6. The relation between ligaments, diaphragm and inferior vena cava (left - ex vivo, right - in vivo)

Another aspect with great practical importance is the increased fragility presented by the liver capsule at the insertion area of the coronary ligament, breaking under minor pressure. We mention that the risk of liver capsule injury is higher in the right portion where the contact area between the ligament and liver is wider than on the left (Fig. 5).

The hepatic pedicle is located on the inferior / visceral face of the liver, relatively central, oriented towards the posterior edge of the organ, in ex-vivo dissection is represented by a mass of connective and adipose tissue that surrounds numerous vascular and nervous emanates. During in-vivo dissection we identify the pedicle as a bundle of vessels of different color and texture, lymphatic vessels and nerves surrounded by a fatty mass (Fig. 7).

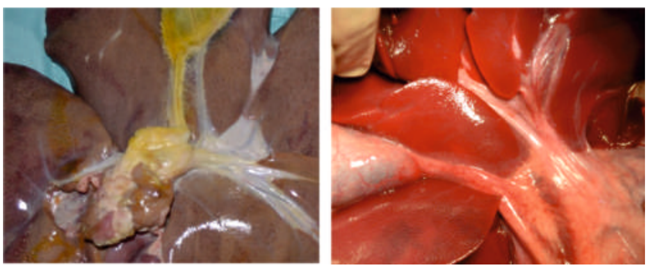

Fig. 7. *Porta hepatis* before dissection
(left - ex vivo, right - in vivo)

The position of the vessels, biliary elements and the grooves of the visceral face of the liver allow, as in humans, an analogy between the letter "*H*": the right arm formed anteriorly by the biliary vesicle and posteriorly by the IVC, the left arm by the union imaginary of the umbilical fissure containing the round ligament with the groove of the venous ligament and the transverse arm is represented by the *porta hepatis*, composed of three main elements: the portal vein, the hepatic artery and the main hepatic duct (Fig. 8).

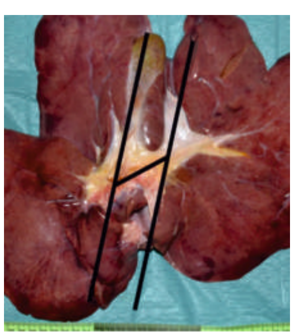

Fig. 8. Visceral surface of liver –
"H" shape (ex vivo)

The portal vein of the elements of the hepatic pedicle, both within the in-vivo dissection and the ex-vivo one, the portal vein was its most posterior structure. The vein has a sinuous path that allows it to be divided into 3 distinct parts, according to its trajectory (Fig. 9), describing:

- A straight part, about 4-6 cm long. It has a cranio-caudal orientation and its trajectory is perpendicular to the visceral face of the liver. This portion does not emit branches or come into contact with the liver;
- A curve part, about 2-5 cm long. The concave part is oriented in the inferior part and towards the middle. Branches emerge from its convexity. We identified one constant branch for the caudate lobe, and various inconstant branches (that usually split in 2 secondary branches before entering the hepatic parenchyma) for the segments VI-VIII.
- A horizontal part, about, 2-3 cm long. It has direct contact with the liver and does not emit branches, it trifurcates emitting branches for the segment II-V.

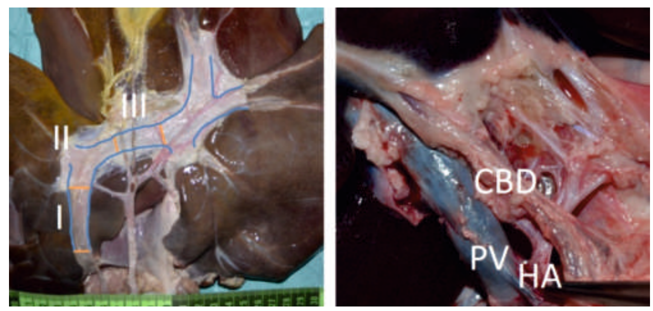

Fig. 9. The hepatic pedicle
(left - ex vivo: division of portal vein;
right - in vivo: PV=portal vein,
HA=hepatic artery, CBD=common bile duct)

The hepatic artery. The arterial component of the pedicle is located medially and is anterior to the portal vein. It divides into several branches before entering the hepatic parenchyma, thus being the element with the greatest variability (of trajectory, path and pattern of branches from the portal triad) (Fig. 10). Most of the time it divides into 3 branches, two smaller for the right hemiliver and one larger for the left one.

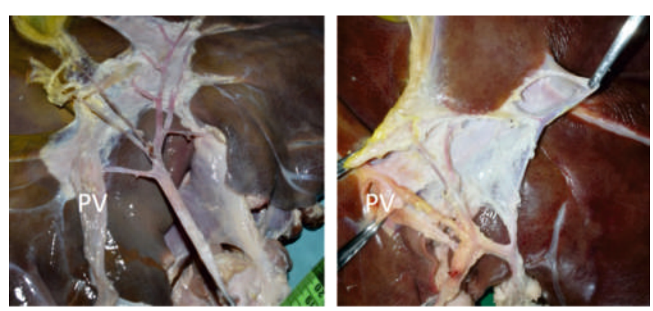

Fig. 10. Tipes of arterial supply
(ex vivo: PV=portal vein)

The extrahepatic bile ducts. As in humans, we identified distinct pathways for the bile drainage of each hemiliver. The biliary ducts of the left hemiliver converge into a constant large biliary trunk, while the ducts of the right part converge into numerous smaller ducts that sometimes join in a single channel that connects with its left counterpart, or form multiple smaller ducts that drain separately into the left duct. The common bile duct formed by the junction of the left and right trunks follows the trajectory of the main left biliary duct, and it is located superiorly and anteriorly from the portal vein (Fig. 11). The walls of the extrahepatic bile duct are thinner and more fragile than in humans, being very likely to be injured during the dissection of the hepatic pedicle.

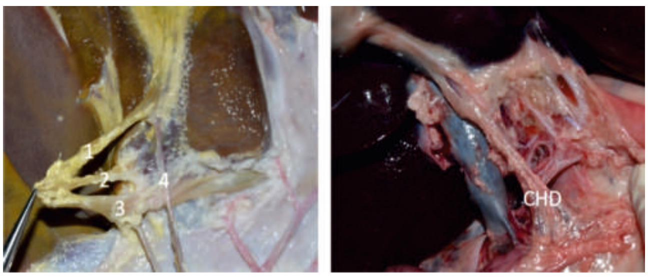

Fig. 11. Extrahepatic biliary tree
(left - ex vivo:1=cystic duct, 2=right hepatic duct, 3=left hepatic duct, 4=cystic artery;
right - in vivo: CBD=common bile duct)

Regardless of the number of branches, and the pattern on which they are formed, the three elements of the hepatic triad form a constant "triad" that is subsequently distributed to each liver segment, like the elements of the human glissonian pedicle.

Lymphatic drainage. Unlike in humans, where under normal conditions the lymphoid elements are poorly represented in the hepatic pedicle, in pig the hepatic pedicle contains numerous lymphatic vessels and a relatively high number of lymph nodes (with a diameter between 5 and 25 mm). During the in vivo dissection of the pedicle, these lymphatic structures must be identified, isolated and eventually excised in order to visualize the elements of the portal triad. Their presence increase the occurrence of lymphoragia during the pedicle dissection, but usually is self-limited.

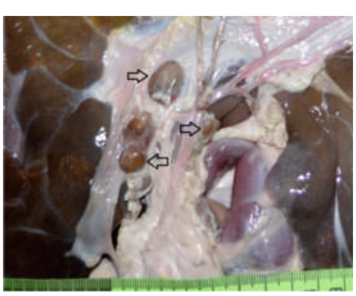

Fig. 12. Lymphatic nodules –
black arrows (ex vivo)

The gallbladder and the cystic duct. Located on the inferior visceral face of the right lobe, the gallbladder presents the same main parts identified in humans (the fundus, the body and the neck).

The fundus portion is coming into direct relation with the left lobe via the umbilical fissure. The cystic duct is 5-8 cm long and it is in direct contact with the cystic artery (Fig. 11). The duct can enter into the common bile duct or directly into the right hepatic duct.

Hepatic veins and inferior vena cava. The venous drainage of the swine liver (out flow) is provided by the hepatic veins (usually 5 in number). In contrast to the anatomical situation in humans, in pigs they flow into the IVC within the liver (increasing the difficulty of bleeding control during the liver surgery).The five veins divide the hepatic parenchyma into 6 drainage sectors located on both sides of the veins (Fig. 13). The caudate lobe has a separate venous drainage, through a small caliber vein that drains directly into the vena cava.

Fig. 13. The hepatic veins - the path of the veins is sectioned – IVC=inferior vena cava (ex vivo)

One of the most peculiar anatomical features encountered in the swine liver is the intra-parenchymal route of the IVC which, right above the renal veins, which enters into the parenchyma through the dorsal face of the right lobe, exiting the organ (after a curved path of approximately 6-8 cm) through the diaphragmatic face of the middle lobe (after receiving the blood of the hepatic veins).The distance between the IVC and the hepatic pedicle is much smaller than in human, thus existing a high risk of IVC injury during a tempestuous hemostasis technique of the hepatic pedicle (Fig. 14).

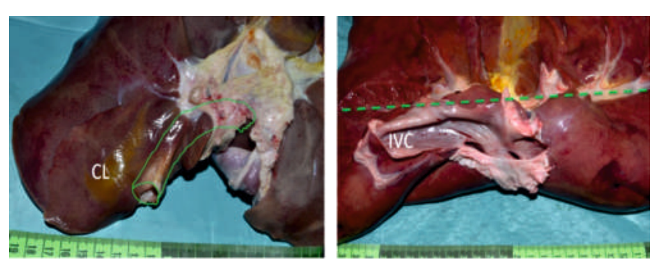

Fig. 14. Aspects of the inferior vena cava
(left - ex vivo: CL= caudate lobe, the route of vein is drawn in green; right-ex vivo: IVC= inferior vena cava is sectioned, the interrupted green line represent the plane of the hepatic pedicle)

The right coronary ligament extends from the diaphragmatic surface of the liver reaching posteriorly from the vena cava, coming in direct contact with it. This aspect has a great practical importance, due to the fact that the sectioning of the ligament by direct traction of the vena cava allows the venous structure to be isolated in the portion where it enters the hepatic parenchyma.

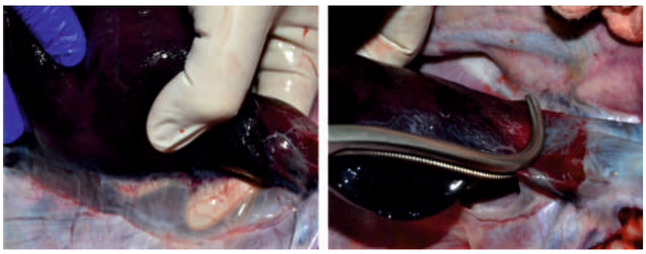

Fig. 15. The right coronary ligament to vena cava (left - in vivo: the translucent membrane represent the coronary ligament; right - in vivo: infrahepatic inferior vena cava clamping)

Segmentation of the liver. The liver is functionally divided into 8 segments numbered in the same manner as Couinaud numbered them in humans (4). Each segment has its own distinct portal and arterial supply, as well as, biliary and venous drainage. Segment I corresponds to the caudate lobe, located at the level of the right anatomical lobe, adjacent to the IVC. Segment II corresponds to the dorsal part of the left anatomical lobe and segment III (larger in volume) occupies the rest of the left lobe. Segment IV consists of the left paramedian lobe (similar to human anatomy). Segment V occupies the ventral part (anterior, to the free edge) of the right paramedian lobe and segment VIII corresponds to the dorsal part of the same lobe. Similar to the segmentation of the liver in humans, the right lobe is divided into segments VI (ventral) and VII (posterior) (Fig. 16).

Fig. 16. The liver segmentation (upper part left - ex vivo: the visceral expression of the segments; upper part right - ex vivo: the diaphragmatic expression of the segments; lower part - ex vivo: the intrahepatic ramification of the portal vein)

Although, we know that the term ligament is used inappropriately when it comes to the liver means of peritoneal attachment, in clinical practice the term is used by medical doctors to describe these means of attachment and we decided to use it. Also we preferred the term pedicle instead of hilum, which we consider inappropriate, because the elements of the hepatic triad do not meet the requirements to form a veritable hilum due to the fact that portal vein brings blood to the organ instead of draining it. Most of our findings are consistent with the data already available in the literature (7) but there are still elements whose description in the literature is not consistent with our observations, like the number of hepatic veins, with cases of subjects with 3, 4 and 5 such structures (9). In our study the 5-veins model was the most common, while the 4-veins one was rarely found. We identified no subject with 3 hepatic veins. We like to mention that, despite the existence of the described drainage territories, the hepatic veins in pigs have numerous accessory vessels,that can drain blood from neighboring sectors, thus creating vascular anastomoses between the standard drainage sectors. These situations can become challenging for the surgeon, especially during central or right lobe resection (the blood from an apparent ligatured sector can flow via these anastomoses into the nearby one generating uncontrolled bleeding). In virtue of the observations above, we consider that the porcine liver is the ideal organ to be used in the training of the residents, in order to perform liver surgery. Descriptive and comparative anatomy studies should continue in order to establish certain standard models and it should be strengthened by pig liver imaging anatomy studies. The resident training program has to include liver surgery on anesthetized swine and also the imaging data that could provide extremely valuable information for choosing the optimal surgical tactic.

CONCLUSIONS

After analyzing the data collected and correlating the current information with previous data in the literature we can say that the anatomy of the swine liver is similar to that of the human liver. If pigs are selected to be at the right age and weight, the liver and the relevant adjacent structures (such as the gallbladder or diaphragm) will be similar in size to those in humans, thus giving the residents an experience similar to the one they will have when operating a human patient with less major risk for developing vicious surgical habits. The specific features of the pig liver that have high relevance for the surgical act, such as the vena cava trajectory, the intrapedicular variability of the hepatic artery and the fragility of the bile tract, all of which are elements that make the liver surgery on pigs difficult in terms of surgical techniques and tactics.

However, these elements are beneficial for the training of young doctors who practice on animal models who are morphologically similar but far more prone to injury and bleeding.

Acknowledgments.

This paper was realized within the Programme PN-III, funded with the financial support of the Project *„High-precision innovative approach of the robotic assisted treatment of liver tumors based on integrated imaging - molecular diagnosis”* PN-III-P1-1.2-PCCDI-2017-0221 / 59PCCDI/2018 (IMPROVE)

Conflict of interest.

The authors report no conflict of interest.

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