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CT EXAMINATION OF THE SWINE LIVER: ANATOMICAL AND VOLUMETRIC DATA PRECEDING EXPERIMENTAL LIVER RESECTIONS

EXAMINAREA CT A FICATULUI SUIN: DATE ANATOMICE ȘI VOLUMETRICE CE PRECED REZECȚIILE EXPERIMENTALE HEPATICE

C. POPA[3),4)], R.C. PURDOIU[1),*)], R. LĂCĂTUȘ[1)], M. SOCACIU[2),3)], G.T. VOICESCU[4)], R. VRÎNCIANU[4)], N.Al. HAJJAR[2),3)], L.I. OANA[1)]

ABSTRACT

In the last decades, thanks to the progress made by minimally invasive surgery, laparosocopic resection surgery is performed on a large scale, but without a consensus regarding a standardized training protocol for this intervention. An effective training protocol should faithfully reproduce the situations the residents will face in the operating room and include all stages of human intervention, including the radiological imaging analysis and intervention planning, in accordance with anatomical landmarks. The purpose of the study is to perform the computed-tomography (CT) description of pig liver anatomy as well as its volumetry, in order to use this information to improve the current training protocols in laparoscopic liver resection for residents and surgeons.12 pigs, 6 females and 6 males, weighing between 35 and 45 kg, were anesthetized and subsequently subjected to CT analysis. Both native and contrast phase acquisitions were performed, resulting in 3D reconstructions, simulations of liver resection and volumetric analysis of the segments, lobes and the entire organ as a whole. The vascular elements of the hepatic pedicle (hepatic artery, portal vein) could be identified and measured. Intra-parenchymal branches of these elements, as well as organ segmentation have been described. The data obtained are in accordance with the existing literature on the macroscopic anatomy of the organ and the intraoperative observations of the surgeons. Imaging of the pig liver is feasible, as the results obtained by CT examination can be of real benefit to the surgeons in a training program. We believe that training protocols in laparoscopic resection surgery should include image analysis, volumetric data as well as 3D reconstruction in the preoperative stage.

Keywords: CT-scan, volumetry, swine liver, training, laparoscopic surgery

1) University of Agricultural Sciences and Veterinary Medicine, Faculty of Veterinary Medicine, Cluj-Napoca, Romania
2) "Iuliu Hațieganu" University of Medicine and Pharmacy, Faculty of Medicine, Cluj-Napoca, Romania
3) Regional Institute of Gastroenterology & Hepatology, Surgery Department, Cluj-Napoca, Romania
4) Training and Research Center "Prof. Dr. Sergiu Duca", Cluj-Napoca, Romania
*) *Corresponding author: robert.purdoiu@usamvcluj.ro*

REZUMAT

În urma progresului înregistrat de chirurgia minim invazivă în ultimele decade, chirurgia rezecțională laparosocopică este realizată pe scară largă, fără să existe însă un consens cu privire la un protocol standard de instruire în vederea realizării acestei intervenții. Un protocol eficient de training trebuie să reproducă fidel situațiile cu care medicul se va confrunta în sala de operație și să includă toate etapele intervenției umane, inclusiv analiza imaginilor radiologice și planificarea intervenției, în concordanță cu reperele anatomice. Scopul studiului îl constituie descrierea computer-tomografică (CT) a anatomiei ficatului suin precum și volumetria acestuia, în vederea utilizării acestor informații pentru îmbunătățirea protocoalelor de instruire a rezidenților și chirurgilor în chirurgia rezecțională hepatică prin abord laparoscopic. 12 porci, 6 femele și 6 masculi, cântărind între 35 și 45 de kg, au fost anesteziați și ulterior supuși examinării CT. Au fost realizate atât achiziții native, cât și cu substanță de contrast acestea conducând la reconstrucții 3D, simulări ale rezecției hepatice și analiza volumetrică a segmentelor, lobilor și a întregului organ în ansambu. Elementele vasculare ale pediculului hepatic (artera hepatică, vena portă) au putut fi identificate și măsurate. Au fost descrise ramificațiile intraparenchimatoase ale acestor elemente precum și segmentația organului. Datele obținute sunt în concordanță cu literatura existentă despre anatomia macroscopică a organului și observațiile intraoperatorii ale chirurgilor. Explorarea imagistică a ficatului suin este fezabilă, rezultatele obținute în urma examinării CT putând fi de un real folos chirurgilor aflați într-un program de formare profesională. Considerăm că protocoalele de instruire în chirurgia rezecțională laparoscopică ar trebui să includă în etapa preoperatorie analiza imaginilor, a datelor volumetrice precum și a reconstrucțiilor 3D.

Cuvinte cheie: Computer Tomografie, volumetrie, ficat suin, training, chirurgie laparoscopică

During the last decades, minimally invasive surgery and implicitly the laparoscopic technique had accelerated and significant progress. Nowadays even complex surgeries like liver resections are performed using this approach. Moreover, recent studies have shown that laparoscopic liver resection (LLR) is safer compared with open liver resection and offers many benefits for the patients, especially a faster postoperative recovery (9). Although LLR is used on a large scale for both minor and major hepatic resection, the existing literature does not provide a standardized training protocol for residents. Therefore, we have previously developed a standardized, Step-by-Step residents' training program that shortens the learning curve for LLR, using an *in-vivo* simulation of the surgery on swine models (10).

Animal models have long been used to replicate human diseases or conditions in attempts to develop better treatments and therapies. Although various studies have shown that swine models represent a good starting point in LLR (6, 16), the current data do not provide accurate, surgical, and radiological anatomy of the swine liver. It is known that computed tomography (CT) - based volumetry of resected liver specimen is accurate and reproducible, therefore recommended for preoperative planning in liver surgery (5).CT based volumetry does not only provide information about the resected liver (RL), but also facilitates the understanding of liver anatomy, as conventional scan images can be difficult to translate into 3D representations for many trainees and independent liver surgeons.

Moreover, the hepatobiliary surgeon can refer back to these three-dimensional images in the operating room, especially when the tumor is close to major vascular structures that require preservation (2).

The existing literature demonstrates that anatomical variations are relatively frequent in the hepatic arterial system. Knowing about these variations before the surgery could be a factor that decreases the rate of contraindications and improve the chance of technical success (13). Therefore, a contrast-enhanced Liver CT (CELCT), represents good imagistic preplanning of the LLR, with numerous advantages. In the light of those above, we introduced a pre-surgery image analysis stage in our protocol, in order to accommodate the trainee with the anatomy of the swine, observe relevant anatomical particularities and also, simulate liver resection. As the current data about the radiologic anatomy of the swine liver is insufficient we initiated this study in order to expand the current knowledge. The present paper aims to describe the radiological anatomy of the pig (as detailed as possible) and also to evaluate the feasibility of introducing an image analysis stage into our protocol.

MATERIALS AND METHODS

Twelve swine (*Sus scrofa domesticus*), both male and female, weighing between 35 and 45 kg were anesthetized by a specialized veterinarian and then subjected to CT-scans via 16-slice scanner (scanner Siemens Somtam Scope (Siemens Healthineers Global, USA).

The pig subjects were part of a training program designed for the surgery residents, in order to perform laparoscopic liver resections. The images were analyzed by a human radiologist, veterinarian surgeons, human surgeons, and residents in surgery.

The animals were placed in the supine position (dorsal decubitus), the scan level was set between the diaphragm and the pelvic bone, and the following parameters used: Nominal Single Collimation Width of 0.6 mm, Nominal Total Collimation Width of 9.6 mm, Pitch factor of 1 and Exposure Rotational of 1.5 s, kilovoltage of 130Kv and milliamperage of 110 mAs.

We performed both native and contrast acquisitions. For the contrast study, we used Mallinckrodt CT9000 advanced injector. The dose of contrast agent was 2ml/kg, with a flow of 3ml/s. We traced the marker concentration at the level of the aorta and when the vessel registered over 100 HU (arterial time) an automatic scan was started. A second automatic scan (representing the venous time) was performed at a 30 seconds delay after the first scan, using the same parameters.

The images obtained had a 512x512 matrix and a 3 to 5 mm slice thickness. For the reconstruction, a 1.5 slice thickness and a soft tissue kernel were used. Multiple planar 3D reconstructions for out liver CT scans were obtained using Syngo Multi-Modality Workplace (MMW) CT Software. The MMW generates a volumetric measurement of the area of interest, providing accurate models for the residents. The image was post-processed using HOROS DICOM viewer software.

We used Syngo.via software version VA30B (developed by Siemens Healthliner International) for semi-automatic 3D reconstruction of the liver and liver volumetry, in order to find the most suitable resection plane for further simulation of hepatic resection.

RESULTS AND DISCUSSIONS

Vascular anatomy of swine liver

In order to appreciate the vascular anatomy of the pig liver, the following sections can be followed: *The common hepatic artery* originates in the celiac trunk at the level of the trifurcation (Fig. 1). Its path is almost vertical, on the left side of the portal vein. Its diameter is 4.2 mm. The first branch appears only after approx. 5 cm, being a gastroduodenal pathway, which has a lower and posterior path, along the stomach and duodenum. The proper hepatic artery, representing the branch with the liver destination, has a diameter of 3.4 mm and is short (6 mm). It is divided into at least 3 - 4 branches, one for each lobe (left lateral, left medial, right medial and right lateral).

The distance (approx. 4 cm) from the branch to the entrance into the hepatic parenchyma is remarkable. The branches expand slowly along the vein leading to the corresponding lobes. The diameters measured on the maximum intensity projection (MIP) reconstruction are (from the right lateral lobe branch to the left lateral lobe): 1.1 mm, 2 mm, 2 mm, and 2 mm. Intrahepatic branches are not visible on CT.

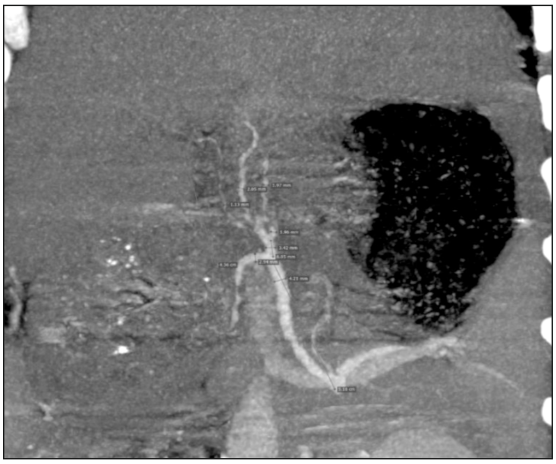

Fig. 1. The common hepatic artery, proper hepatic artery, and the distribution of the lobar branches. MIP coronal, slightly oblique in the proper hepatic artery bifurcation plane reconstruction

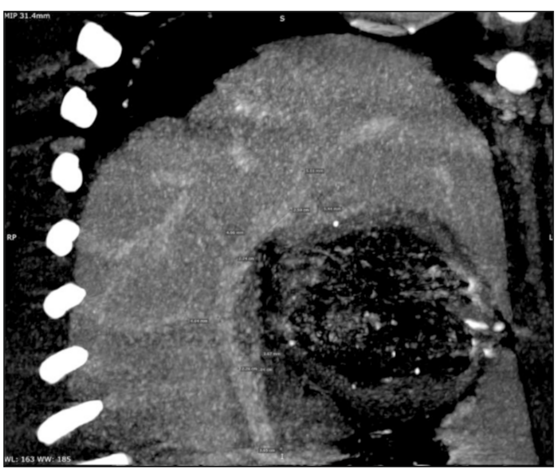

Fig. 2. The portal vein and the distribution of the intrahepatic branches. Anteriorly left oblique coronary MIP reconstruction to be able to capture the main lobe branches

The portal vein (PV) originates at the confluence of the superior mesenteric vein with the splenic vein, located at a great distance from the liver (at least 8 cm lower) (Fig. 2). The initial diameter of the portal vein is 1.04 cm. The PV extends on the visceral face of the liver along the lobes and gives, in turn, one branch to each of the following:

- for the caudate lobe a branch at 3.6 cm from the origin, with a size of 3.6 mm;
- for the right lateral lobe, after another 2.2 cm, a branch with a size of 4.6 mm;
- for the right medial lobe, after another 2.7 mm, a branch with a size of 4 mm;
- the final bifurcation, after another 2.6 cm, with the branches for the left medial lobe, respectively the left lateral lobe measuring 5.1, resp. 5.4 mm in diameter.

While the portal vein extends on the surface of the liver, its lobar branches are intrahepatic and help to delineate the segments.

Fig. 3. MIP Reconstruction in the sagittal plane, to emphasize the intrahepatic path of the inferior vena cava

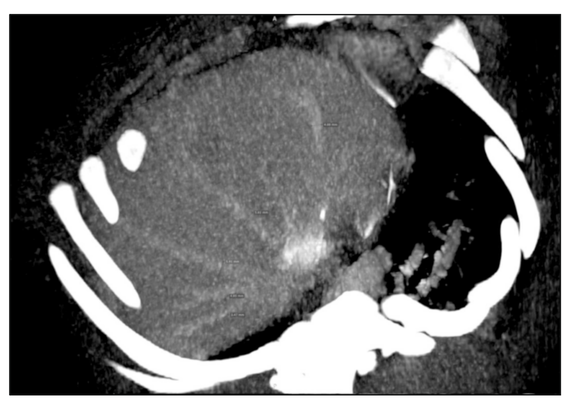

Fig. 4. MIP reconstruction in an oblique transverse plane from bottom to top and from right to left to highlight the outflow of the hepatic venous branches in IVC

The inferior vena cava (IVC) has a long intrahepatic path (measured at 17 cm in this case), along its poste-

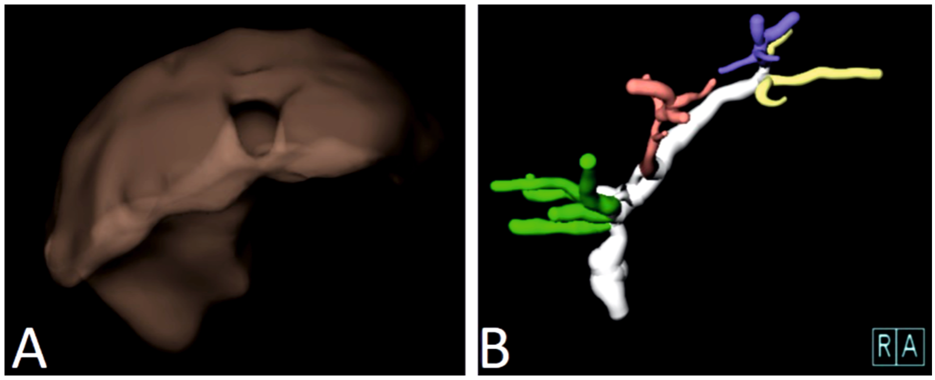

Fig. 5. Liver parenchyma (A) and portal venous tree (B) with the dividing branches of the main lobes

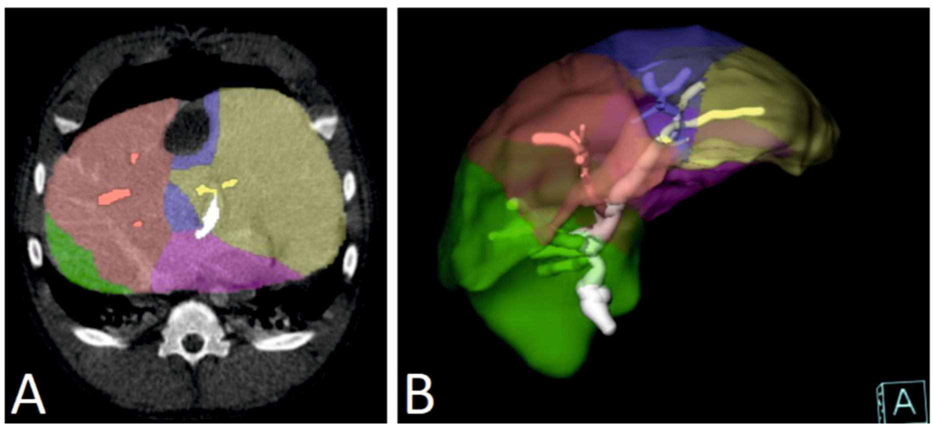

Fig. 6. Delimitation of the segments (in our case of lobes) of the liver on 2D sections (A) and on the reconstructed 3D volume (B)

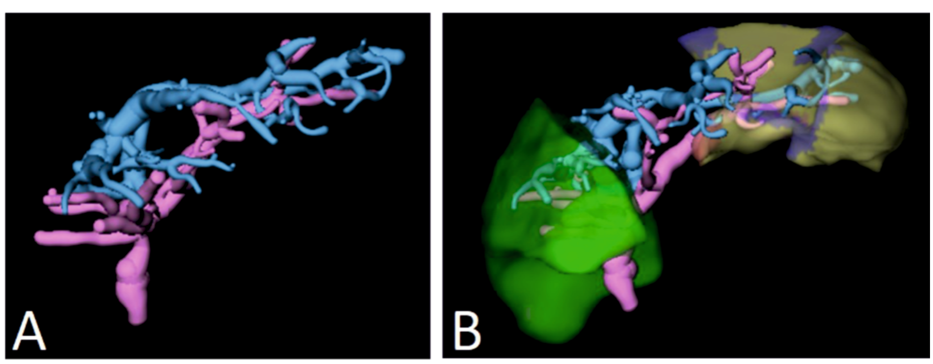

Fig. 7. The anatomy of the portal (pink) and hepatic (blue) venous branches in 3D isolated by the hepatic parenchyma (A), respectively seen through a "cut" window next to medial lobes (B)

rior and diaphragmatic face. Its diameter varies between 1.3 and 1.5 cm (Fig. 3).

The suprahepatic veins are also intrahepatic, at a small distance from the diaphragmatic surface and are in larger numbers compared to humans (in this case at least 5, the right grouped tightly) (Fig. 4). Their diameter varies between 3.5 mm and 5.9 mm.

Liver volume - The following volumetric parts could be identified: the whole liver, the main vascular branches (especially the PV and hepatic veins), lobes and segments based on vascularization. Following the delimitation of the parts, virtual "sections" can be made and the volumes delimited can be measured. In the case below, the total liver volume was 684 cc. We can see the whole liver parenchyma and the "skeleton" of the intrahepatic portal branches (Fig. 5), which was the basis of the division into: the right lateral lobe – RL (green); right medial lobe - RM (red); left medial lobe - LM (blue); left lateral lobe - LL (yellow). The branch for the caudate lobe – CL (cyclamen) is not seen in the image.

Based on the distribution of the portal vessels, the workstation is able to delimit the liver lobes, overlapping color maps over the parenchyma. The aspects can be appreciated both in 2D sections (Fig. 6A), as well as in 3D reconstructions (Fig. 6B).

Once the different anatomical elements of the liver are delimited, they can be combined for a better understanding of the anatomy of a particular region. For example, Fig. 7 illustrates both the portal and hepatic venous branches seen globally (A) and through a "cut" window near the medial lobes (B).

The main purpose of the volumetry was to measure the volumes of the hepatic lobes to further compare them with the real situation. Several virtual sections were created along with the previously delimited segments (Fig. 8). Thus, sums of volumes between different lobes were obtained (Fig. 9).

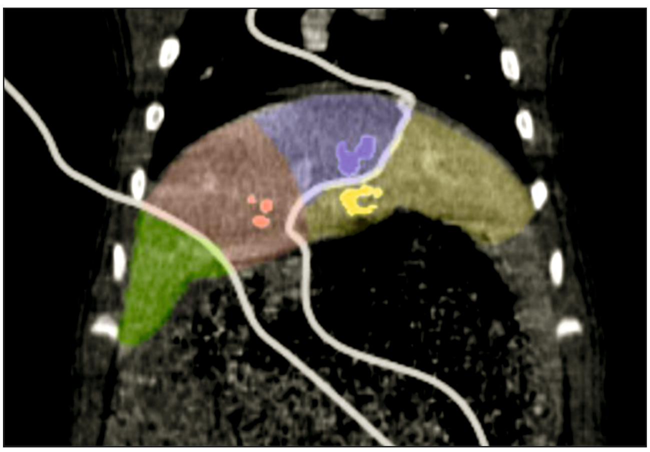

Fig. 8. Delimitation of the sections between the created segments

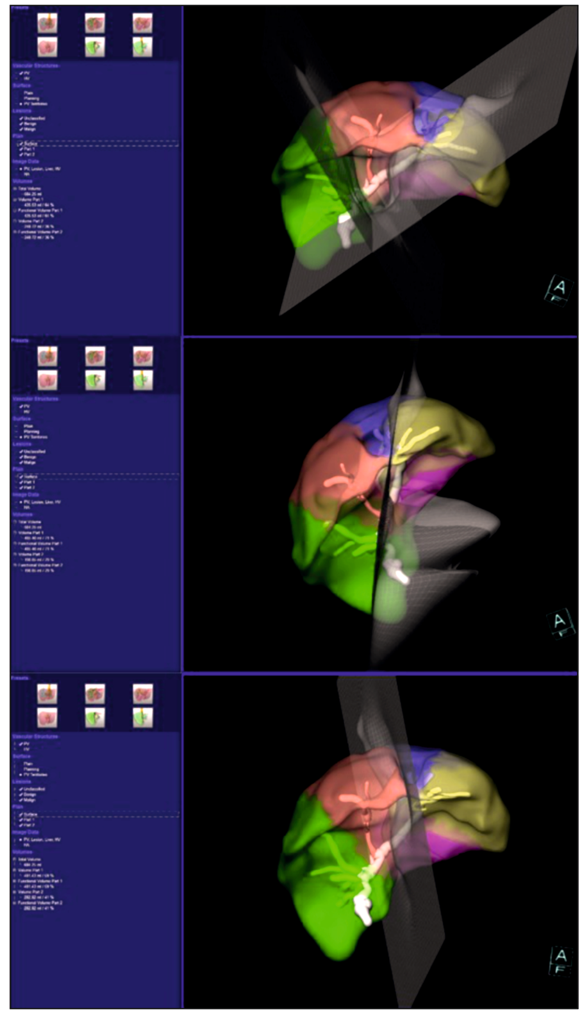

Fig. 9. Different delimitations used to measure the individual volumes of the lobes

The obtained results were:

- ✓ RL+RM+LM+LL+CL=684 cc
- ✓ RM+LM+CL=296 cc
- ✓ RL+RM=401 cc
- ✓ RM+LM=249 cc

On their basis, we calculated the volume for each lobe: CL= 47 cc, RL=236 cc, RM=165 cc, LM=84 cc, LL=152 cc.

DISCUSSION

Major hepatectomy is now routinely carried out for various malignant and benign indications, with an associated mortality of less than 5 % (2). In patients undergoing large liver resections, the surgical plan must be precisely outlined to make a proper preoperative risk assessment (7). Numerous studies have shown that the postoperative remaining liver (PORL) is an accurate predictor of dysfunction after the liver resection (8, 14). Because impaired liver function after resection is caused by insufficient liver volume, reliable volumetric assessment of the hepatic lobes of potential living donors is crucial for successful liver transplantation (4). Wrong estimation of the PORL can have fatal consequences (8). In healthy humans, resections of up to 80% of the liver are accepted, while in cirrhotic liver resections must not exceed 60% of the liver (1, 12). To minimize the risk of postoperative liver failure, preoperative estimation of the residual liver function has become a fundamental part of liver surgery (8). The liver volumetry is useful in both transplant and oncologic liver surgery. Thanks to the advances in surgical procedures, intraoperative anesthesia and postoperative care, the surgeons are now able to perform surgery on patients with previous inoperable diseases. Therefore, the number of surgeries for primary and secondary malignancies has increased (8). The existing literature demonstrates that anatomical variations are relatively frequent in the hepatic arterial system. Therefore, a contract-enhance liver CT (CELCT), represents good imagistic preplanning of the LLR, with numerous advantages (13).

As a good training protocol has to simulate all the stages and steps of the process, we consider the image-analysis stage mandatory. The data collected about the swine liver do not have a highstatistical significance due to the insufficient number of tested subjects (12 subjects) but shows that there is a consistency in the radiological anatomy of the swine liver and allows us to affirm that by pre-operative CT analysis we can identify anatomical particularities of major relevance for the surgeon.

By upgrading our existing training program (10) with a pre-operatory CT scan, we have not only improved our trainees understanding of the swine liver anatomy but also taken our simulation to the next level. When confronted with CT-volumetry of the porcine model, the residents had to assess their resection and adapt it in order to avoid the post-operative liver failure and complications associated with PORL. Therefore, the difficulty level of our training increased, but our trainee's feedback shows us that this step is important for a faithful simulation. It is known that with the correct preparation and approach a trainee is able to obtain a higher level of expertise in liver laparoscopy without putting the lives of the patients at risk (5). As a result, pigs have been frequently used as a model for colorectal laparoscopic surgery, sheep as a gynecologic and transvaginal NOTES model and rabbits as a pediatric thoracoscopy model (6). From all commonly used research animals, the swine liver provides for the young residents a great training opportunity in laparoscopic liver resections. Pigs are an ideal animal model for human health and diseases because their anatomy and physiology are similar to humans (15). In-depth knowledge of its anatomy allows the young surgeon to perform accurate and knowledge-based interventions (3, 11).

This paper is the first to describe the CT liver volumetry of a swine model and describe the radiological anatomy of the porcine liver. With this new information, we want to facilitate a better and more realistic training on LLR. The preplanning phase of our Step-by-Step training program consisted of ex-vivo model analysis and simulation of the procedure, as well as analysis of radiologic images of the swine liver (2). By introducing the liver volumetry in the preplanning phase, we helped our trainees to better understand its anatomy, offering a new perspective into a safer surgery for the patient.

CONCLUSIONS

The CT-scan devices and software for 3D-reconstruction, volumetry and resection simulation, current in use for human surgery, can be applied on swine. The data gathered in our study, suggest that the information from radiological anatomy is consistent and thus image-analysis before the surgery is useful for the training of the surgeons.

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