An innovative approach for laparoscopic liver resections. Training protocol

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AIM: *To evaluate the benefits of systematical use of ex vivo liver model and CT imaging in the planning process for swine laparoscopic liver resections done by residents during a dedicated training program.*
MATERIAL AND METHODS: *Thirty general surgery residents, part of a dedicated and continuous training program, were equally divided into two groups: first one which performed laparoscopic liver resections without planning stage and the second one which systematically used an interactive tutorial for establishing the strategy for the resection followed by performing open liver dissection and the same resection on an ex vivo swine model. Afterwards, laparoscopic procedures were performed on twenty anesthetized domestic pigs.*
RESULTS: *All teams successfully completed the procedure, with no conversions to open approach and without trainers' intervention. The second group was faster than the first group on both minor and major resections (p=0.0001). The blood loss was significantly lower on the second group (p=0.005).*
DISCUSSION: *The residents surpassed our expectations regarding the operation time, blood loss and conversions, validating our training program. The step-by-step program was developed using the IDEAL paradigm, being now at the end of the 2b phase (exploration), when the residents realize the benefits of this model. The reduction in blood loss and loss of functional parenchyma demonstrates the utility of a warming-up phase.*
CONCLUSIONS: *The "warming up" by adding the imagistic and anatomical data to the core protocol offer more clarity before laparoscopic liver resections and makes an upgrade for our "step by step" protocol.*

KEY WORDS: Experimental model, Laparoscopic liver resections, Residents

Itroduction

Nowadays, laparoscopy is the main approach of the abdominal surgical procedures. Several randomized studies have demonstrated that this approach is associated with shortened hospital stay and decreased morbidity for various gastro-intestinal diseases [1]. Multiple studies have shown that laparoscopic liver resection (LLR) is safer and more feasible compared with open liver resection, particularly regarding the post-operative recovery [2]. Although it presents as a minimally invasive technique with reduced risks for the patient, some types of surgical resections remain technically demanding procedures that require experienced surgeons [3].

In order to shorten the learning curve of the surgery residents, multiple learning methods have been tested, starting from dry box training to 3D simulation and an assessment-feedback system. It is known that a dedicated, step-by-step program is optimal and residents should gradually increase the difficulty of the surgeries, while

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maintaining safety for the patient [4]. Despite these attempts to standardise the training of the inexperienced surgeons in LLR, we don't have a generally accepted training model yet [5]. With specific training, young surgeons, which are not pre-trained are able to overcome the learning curve for minor and major liver resections faster than the self-taught surgeons. The findings of this study are applicable to all surgical specialties and highlight the importance of specific training in the safe expansion of novel surgical practice [6].

The existing literature suggests that a training model in LLR should meet the following requirements: to be stepwise, to have increasing difficulty (starting on healthy organs and subsequently on organs with different degrees of cirrhosis and various tumoral lesions), to minimize the harm to patients, to be cost effective [4]. We believe that translating from dry box training directly to fellowship, namely performing surgery on humans, is not the best way to shorten the learning curve. A training program should also include a bridge between training on ex-vivo models and human surgery.

The present study assessed an experimental laparoscopic liver resection model on swine. Using swine models to bridge the gap between theoretical knowledge and practical skills provides several advantages: the Romanian and European laws regarding the research on living animals allows to use swine as training models, it is logistically easy to provide swine (low cost) and has similar physiology (skin texture, blood flow, capillary vascularization etc.) with humans. For our training, beside the human doctor we have collaborated with a veterinary doctor, to provide the best care for the porcine models. Although there are differences regarding the anatomy of the liver, the existing literature shows that swine represent a good starting point in LLR training [7,8].

In order to furthermore shorten the learning curve in LLR, we have developed a warming-up phase, before the surgery, during which the residents familiarise with the swine anatomy and plan the procedure on ex-vivo models combined with imagistic data. The main aim of our study was to develop a standardized pre-operatory training program in laparoscopic liver resections for surgery residents with different levels of experience and our secondary aim was to evaluate the benefits of this type of program among surgery residents.

Methods

The Training Program

Starting with 2016, we began a training program in our centre, developed specifically for young, untrained surgery residents from the regional university hospitals. During the last years, we focused on improving our training program, using both objective observations and feedback from our participants. Therefore, we developed an experimental laparoscopic liver resection step-by-step protocol, which consists in several steps: we begin by inducing pneumoperitoneum and placing the trocars. Afterwards, we manipulate the small intestine in order to get familiar with the laparoscopic instruments, then perform laparoscopic cholecystectomy, an excellent first surgery due to its simplicity. The next step was the mobilization of all hepatic lobes following the anatomical delimitations and dissecting the ligaments (the falciform and left triangular ligament). Each resident performed a small hepatic marginal resection on each swine using *Habib 4X* device and coag-cutting instruments. As a final step each team made a large resection (over 30cm^2) or a left lobectomy on each model (Fig. 1).

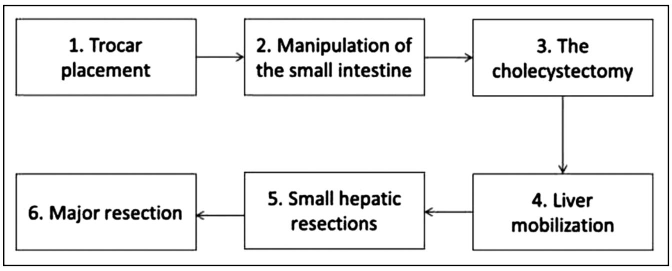

Fig. 1: The diagram with the step by step protocol.

Our observations determined us to add a new step in order to improve our program: warm-up session. It consists of a two-phase program: in the first one, the residents, with the guidance of a radiologist analysed the CT scans to be familiarised with the liver anatomy and simulated more types of resections. In the second phase each resident performed an extensive dissection using as *ex-vivo* model a fresh whole swine liver. The dissection protocol was designed to obtain information about the hepatic ligaments, the elements of the hepatic pedicle (portal vein, hepatic artery and biliary branches), hepatic veins, inferior vena cava, and the liver segmentation. At the end of this phase all the residents made one resection which was simulated in the previous phase.

The Participants

Thirty residents included in the general surgery residency program were selected upon their will and acceptance to participate in the study. The residency program consists of a 6 years training system. All the residents are part of a specific and continuous training program for laparoscopic liver resections. They were randomly selected and every participant signed a written consent for the participation in this study. They were equally divided into two groups: first group performed laparoscopic liver resections without a planning stage, while the second group analysed data from CT-scans, 3D reconstruction and anatomical models, following our two-phase training program. Each group was divided into five teams of three residents. All the participants followed the same step by step protocol for laparoscopic liver resections under direct supervision of a senior hepatobiliary surgeon.

Ex vivo models and live animals:
A total of fifteen models were harvested from animals weighting 110-120 kg, directly from the source (slaughterhouse) by a veterinary - medical doctor team, during the evisceration process of the animal. Each resident from the second group used one model for the warm-up session.
We used twenty anesthetized domestic pigs, two for each team, as models for liver LLR. The swine were of both sexes, weighing between 30-40 kg, as we consider to be the ideal weight of the animal, so the organs will have similar dimensions with human organs, respectively, the consumables that are being used (both anaesthetic and surgical) and the instruments are similar to those in human surgery.
One day before warm-up session all of them received a CT scan with intravenous contrast using the same protocol. The CT evaluation was performed using a 16-slice scanner (Siemens Somtam Scope (Siemens Healthinerss Global USA). The pig was placed in dorsal decubitus and the scan level was set from the diaphragm muscle to the pelvic bone. During the scan acquisition the table was moved craniocaudally. Nominal Single Collimation Width was set at 0.6 mm and Nominal Total Collimation Width was set at 9.6 mm. Pitch factor was 1 and Exposure Rotation time per second was 1.5 s. CT Acquisition Type was Spiral Acquisition and the tube kilovoltage was set at 130 kV, with a milliamperage of 110 mAs.
The contrast study was performed using bolus tracking technique, the contrast was injected using a Mallinckrodt CT9000 adv injector, dose of 2 ml/kg, with a flow of 3 ml/s, a marker was set on the image at the level of aorta, when the marker registered over 100 HU (arterial time) an automatic scan was started. A second automatic scan (venous time), using the same parameters, was set to start after 30 second delay of the first one.
For image acquisition, anative and a post contrast CT scan were performed. The images obtained had a 512x512 matrix, a 3 to 5 mm slice thickness and reconstruction were made using a 1.5 slice thickness and a soft tissue kernel. Multiple planar reconstruction was obtained using Syngo Multi-Modality Workplace (MMW) CT Software to make 3D reconstructions from our liver CT scan. The MMW then 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 Simens Healthliner International) for semi-automatic 3D reconstruction of the liver and liver volumetry, in order to find the most suitable resectional plane for the further simulation of the hepatic resection.
In the operative day the swine were prepared by veterinary doctors, and were positioned in a supine position. Pigs were fasted for 24 hours before surgery with free access to water. Animals received atropine 0.02 mg/kg subcutaneous, diazepam 0,5 mg/kg deep intramuscular, azaperone 4 mg/kg intramuscular and ketamine 10 mg/kg intramuscular. Induction was achieved by intravenous propofol administration and rocuronium 0,6 mg/kg. General anaesthesia was maintained with 1,5% isoflurane in oxygen at a flow rate of 2 L/min.
All training activities were approved by the Ethics and Animal Well-Being Committee of our Centre.

Statistical Analysis

Statistical Package for Social Sciences (SPSS v20.0) was used for analysing the data collected. We used Shapiro-Wilk and Kolmogorov-Smirnov tests to verify normal distribution of data. Numerical data were presented by medians with 25 and 75% percentiles, arithmetic means, standard deviations (SD), minimum and maximum values. We used T-test or MannWhitney U test for pairwise comparisons of normal / non-normal distributed numerical data. Statistically significant results were obtained when $p < 0.05$.

Results

The average time for imagistic planning was 37.6 minutes (SD=3.5 min) and for open dissection and resection was 58.8 minutes (SD=3.8 min). The imagistic data offered a very useful 3D reconstruction with anatomical positions of the vasculo-biliary tree and liver segmentation and gave us the possibility to create practical scenario for resections. The most important information was to find and see the sectional plane and to calculate the remaining liver volume after resection (Fig. 2).
The residents established the most frequent description of swine liver anatomy by putting together the information from *ex vivo* model dissection. The liver parenchyma is divided into four main anatomic lobes: left lateral, left medial, right medial and right lateral. All those lobes are connected only in the posterior part, which allows a very good separation between them by deep fissures. Like in humans, we found eight distinct segments with independent vascularization and biliary drainage. Portal vein has a specific "*S*" shape; in most cases (65%) hepatic artery was found like a trifurcation and extrahepatic biliary tree has a very thin wall. In the right hemi-liver, the inferior vena cava passes through the liver parenchyma. Most frequent (95%), we found five hepatic veins, which are running completely intraparenchymal (Fig. 3).
The final step of the planning stage was to dissect and isolate the glissonian pedicle of the liver parenchyma proposed to be removed. After "vascular control" the resi-

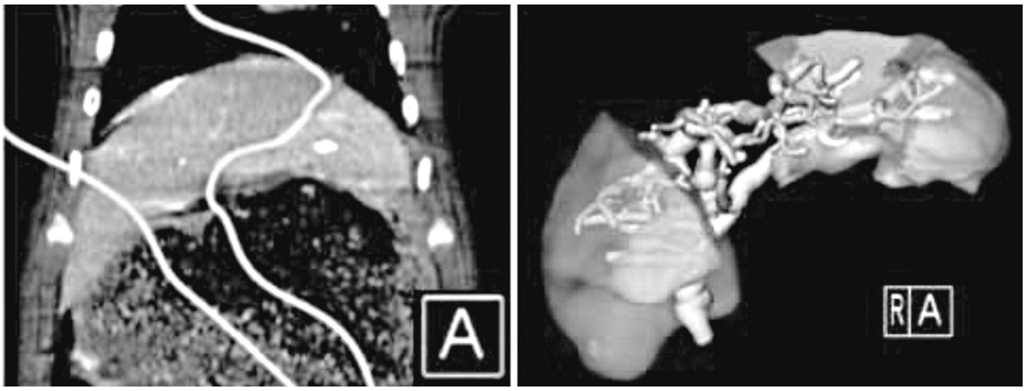

Fig. 2: Left side: Sectorial planes. Right side: 3D reconstruction.

Fig. 3: Left side: 1= portal vein; 2= hepatic artery; 3= common hepatic. Right side: segmentation based on portal vein division.

Fig. 4: Left side: Glissonian pedicle. Right side: sectional plane

TABLE I - *Surgery time and bleeding*

Main Step	First group	Second group	P Value
First minor resections Median (P25%,P75%) -minutes-	50 (47.5, 90)	58 (55, 64)	0.001
Second minor resections Mean (±SD) -minutes-	50.66 (± 5.20)	39.80 (± 5.01)	0.0001
Major resection Mean (±SD) -minutes-	190.00 (±23.09)	124 (±13.49)	0.0001
Blood loss Median (P25%,P75%) -mL-	145 (130, 170)	58 (55, 64)	0.005

SD = standard deviation P25%,P75% = 25% and 75% percentiles

dents were able to cut the liver and then to make the connections between imagistic sectional plane and the real one (Fig. 4).
Regarding the operation on live anesthetized pigs, all teams successfully completed the interventions and followed the standardized protocol without trainers' interventions and with no conversions.
Each resident performed two minor hepatic resections as first-hand surgeon and each team of three performed two large resection. Shapiro-test revealed that the data for the second resection and the large one was normally-distributed and for the first one was not. The group who performed the planning session was able to perform the first minor resection in a median time of 36 min (35 minutes for the 25% percentile and 44 for the 75% one) , the second one in a mean time of 39.8 minutes (SD of 5.01 min) and the large resection in 124 min (SD of 13.4 min). All these steps were highly statistically significant (p=0.001), proved to be faster than those performed by the first group (Table I).
The estimated blood loss during this stage was also calculated (the amount of fluid collected in a suction con-

tainer minus the volume of fluid used for irrigation) and data analysis showed that no normal distribution was found. The median of blood lost was 145mL for the residents with no warming-up and 58 mL for the second group (p=0.005).

Discussions

The impact of residents participation in training programs on perioperative outcomes has been greatly debated in recent years through various methods. Despite their lack of training in laparoscopic surgery, the residents surpassed our expectations regarding operation time, blood loss and conversions, thus validating our experimental training model.
In the development of our training program, we have used the "IDEAL" paradigm. We began from the idea of improving the residents' learning curve of LLR using swine models. Based on this idea, we developed an initial Step-by-Step training program, that significantly improved the outcome of the procedures performed by young surgery residents. In the next step, we upgraded our program by adding a pre-operative planning stage, during which the operators got familiarised with swine anatomy. We are now in the end of the phase 2b of the paradigm, the technique is more stable, the residents realise the potential benefits of being part of a dedicated training program and the step by step approach can be easily replicated by others [6,9].
This study shows that a complex, hands on training program on animal models represents a good method of skills improvement for surgery residents. Recent literature results found that, although both liver and pancreas resections with resident participants resulted in a longer operative time, other parameters such as duration of stay and perioperative major morbidity were unaffected[10]. Moreover, several studies suggested that the learning curve of young, unexperienced surgeons is shorter, when compared with senior doctors [6,11]. This data suggest that we should develop our program in order to address the requirements of the resident surgeons.
A systematic and learning curve-based training course, combined with simulated training, animal-based liver resection and expert-guided hands-on work represents a good structure for learning LLR [12]. Also, according to the existing literature [13], a training program with gradually increasing complexity is the best way to gain experience in the surgical field. Operations should be divided into steps (i.e., trocar position, preparation of Pringle manoeuvre, intraoperative ultrasound, mobilization of the liver, pedicle dissection, hepatic veins exposure) [4]. Our upgraded Step-by-Step training program fulfils all these requirements.
One big problem for our trainees was to determine the differences between human and porcine liver anatomy. For a resident that has no experience with swine models, this difference can be overwhelming, but with the appropriate preparation, the surgeon can obtain a very interesting simulation of a human laparoscopic liver surgery during an operation with a pig as a laparoscopic model. The literature suggests that with a correct preparation and approach, even with few experimental animals a trainee is able to obtain higher level of expertise in liver laparoscopy without jeopardizing the lives of patients [8]. Moreover, preoperative anatomical reconstructions and reviewing of the surgical instruments and their use, helps improving resident's confidence during the surgical procedure itself [4].
There is no doubt that the 3D anatomy of internal structures and distances between vessels and other structures, are accurate [14]. This 3D reconstruction of the vascular architecture allows the young resident to visualize the "invisible" aspects of that particular liver and makes them aware of the possible difficulties they may encounter with the liver during parenchymal transection [15]. To be more specific, in our study, after a simulated liver resection all participants proceed to make the same resection using an *ex vivo* swine model. This phase consists of adding the imagistic and anatomical data of the liver to our core protocol offered more clarity before laparoscopic liver resections. The reduction in blood loss and loss of functional parenchyma proves the importance of this preoperative sequence, providing sufficient data to admit this planning stage as mandatory for laparoscopic liver resection on swine during a training program.
Another big problem of surgical residents, that our Step-by-Step program addresses, is the need of psychological training. It is known that the senior surgeons work more efficiently and safely under pressure, while junior residents exhibit deterioration in performance under a temporal demand [16].Using animal models we can simulate the pressure from the Operating Room, providing a psychological preparation for the operating room pressure. A simulation model for improving the surgical technique would encourage the practice, evaluation, but also the feedback of the resident. The literature shows that there are some key steps in surgical training: dry box training, 3D simulation, and an assessment—feedback system. It has been recently reported that both training using a surgical box model in laparoscopic surgery and a virtual training are effective for inexperienced surgeons [17]. More than that, a take-home box trainer simulation-training program was associated with improvement in laparoscopic skills [18]. Beside the gained practical skills, this training model offer the resident, the chance of being the first-hand surgeon. The team is coordinated by himself, and thus gains the confidence of making important decisions in the real surgery theatre, helping him maturing in a complete surgeon, a person with great practical skills and confidence to make important decisions in a short amount of time and under pressure.
We helped our trainees to learn the swine anatomy before performing surgery. Firstly, we developed an anato-

mic-imagistic pattern based on *ex vivo* model dissections combined with imagistic data, that offer a unique understanding of the anatomy before the intervention, transferring the knowledge from outside into the inside of operating room. Secondly, through this enhanced training model we helped our trainees to learn the swine anatomy before performing surgery in order to lower the operation time and the rate of complications. The statistically significant improvement of the resection time for both minor and major resections and a 60% reduced blood loss obtained by the group that had a planning stage compared with the one that did not prove the importance of this step in our training program. This "human *vs* swine" concept provides an easy method of learning anatomy, which should be applied in swine liver anatomy for residents in training. The most frequent reason for LLR conversion was bleeding control. Therefore, using a good preoperative planning, the rate of conversions can be reduced. Moreover, the reduced operative time translates in a shorter anaesthesia time, reducing the rate of complications and postoperative morbidity. By reducing the loss of parenchyma, the postoperative morbidity and mortality can be decreased. Also, the improved precision, prepares the young surgeon to address more difficult cases, which require more advanced resection procedures, which spares more parenchyma.

We believe that this training program provides a bridge between theory and fellowship. In order to further shorten the learning curve, the "human vs swine" learning method provides an innovative way of learning swine anatomy. Several studies show that a number between 50 and 60 laparoscopic interventions are needed by a surgeon to master the basics of laparoscopic liver resections[6,19-21]. Our training program can provide the needed theoretical, but also handson training in order to develop the basic skills of LLR, before proceeding to human surgery.

Conclusions

The "warming up" by adding the imagistic and anatomical data to the core protocol offer more clarity before laparoscopic liver resections. This also makes an upgrade for our "step by step" protocol and provides sufficient data to admit this planning stage as mandatory for laparoscopic liver resection on swine during a training program.

Surgical resident training continues to be a pressing issue on which more studies need to be conducted, with more participants in each group and on a diverse range of procedures and training models. The next phase (assessment) according to IDEAL paradigm will be a great opportunity to propose the laparoscopic approach as an important stage regarding the educational process in residency.

Riassunto

Questo studio è finalizzato a valutare i benefici dell'uso sistematico del modello epatico ex vivo e della tomografia computerizzata per la programmazione delle resezioni laparoscopiche di fegato nel suino eseguite dagli specializzandi programma dedicato alla formazione.

Trenta specializzandi in chirurgia generale, facenti parte di un programma di formazione sono stati divisi in due gruppi: il primo che ha eseguito resezioni laparoscopiche del fegato senza fase di pianificazione e il secondo che ha sistematicamente utilizzato un tutorial interattivo per stabilire la strategia per la resezione da eseguire, seguito dalla dissezione epatica da banco, e poi la stessa resezione su un modello suino ex vivo. Successivamente sono state eseguite procedure laparoscopiche su venti suini domestici anestetizzati.

Tutte le squadre hanno completato con successo la procedura, senza dover convertire a laparotomia e senza l'intervento dei tutors. Il secondo gruppo è stato più veloce del primo gruppo su resezioni minori e maggiori (p = 0,0001). La perdita di sangue è risultata significativamente minore nel secondo gruppo (p = 0,005).

I residenti hanno superato le nostre aspettative per quanto riguarda il tempo di intervento, la perdita di sangue e le conversioni a laparatomia, convalidando il nostro programma di formazione. Il programma è stato aggiornato passo-passo puntando all'ideale, alla fine della fase 2b (esplorazione), quando i residenti concretizzano i benefici di questo modello. La riduzione della perdita di sangue e della perdita di parenchima funzionale dimostra l'utilità di una fase di riscaldamento.

CONCLUSIONE: la curva di apprendimento, aggiungendo i contributi dell'imaging anatomici al protocollo base consente una maggiore chiarezza prima dell'esecuzione delle resezioni laparoscopiche del fegato e migliora il nostro protocollo "passo dopo passo".

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