PIG LIVER SECTORIZATION AND SEGMENTATION AND VIRTUAL REALITY DEPICTION[1]

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ABSTRACT – Objective: To determine pig liver sectorization and segmentation through the representation of their correlation to portal and hepatic veins, and through the development of virtual reality (VR) animation. **Methods:** Twenty models were obtained by injection of portal and hepatic veins from Landrace pig livers with a methyl methacrylate solution, and by corrosion of the hepatic parenchyma with chloride acid 35%. VR animation of one of these models was conducted through graphic software (3D Studio Max 3.0). **Results:** Constant presence of eight segments and six venous drainage sectors was observed. Pig portal vein bifurcation was not noticed. Hepatic veins were named according to their embryological origin. Correlation between venous system and hepatic parenchyma was established by means of VR animation. **Conclusion:** These models facilitated both the study of pig hepatic sectors and segments, and the proposal of hepatic veins nomenclature. These models have also been used for the development of VR animated models which show the correlation between the hepatic parenchyma and the pig liver venous system as well as the observation of them from several points of view.

KEY WORDS – Comparative anatomy. Liver. Pig. Virtual reality.

INTRODUCTION

Studies of human liver venous system anatomy evidence the need for a definition of liver segmentation and sectorization, and mark the beginning of regrade hepatectomy[1]. Confection of injected models with or without corrosion constitute important contribution to the pertinent anatomy studies[2,3,4] as well as to hepatectomy betterment. Such knowledge has contributed to partial transplantation as an alternative to the shortage of organ donors[5,6,7].

The study of the pig liver anatomy constitutes invaluable background for the teaching and the training of surgery teams for hepatectomy and partial hepatic transplantation[8,9]. Utilization of pigs in research should be emphasized due to feasibility and to functional adaptation in partial transplantation recipients[10,11] and in living donors[11,12]. This experimental animal is preferred for many reasons: because its liver is similar to the human liver, it is easily available in its different growth phases, low cost, and also because it does not develop affection[13] so easily. Such practice is important as it does not involve *anima nobile* utilization during the learning stage curve[14].

Pig liver anatomy has been studied through injection and corrosion methodology[11,13,15,16] for determination of its segmentation[11,15]. However differences as to the description of this organ have been noticed.

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In order to determine pig liver segmentation and sectorization in the present study models of the intraparenchymal distribution of portal and hepatic veins were obtained by both injection and corrosion methodology. Due to the models extreme frailty for handling and transportation, and also because swine liver anatomy VR images have not been found, animation in virtual reality was developed. Such device facilitates correlation between pig hepatic parenchyma and its venous system, and has already been used in medical teaching.

METHODS

1. VR MODEL IMAGE GENERATION: To generate the VR model, an acrylic model of pig hepatic and portal veins, photographs of this model, photographs of pig liver, a personal computer, and a three-dimensional (3D) graphic software (3D Studio Max 3.0) were used.

Model construction process

Twenty Landrace male pigs (age range, 2-3 months) weighing between 20 and 25 kg were obtained at a private slaughterhouse, lawfully established and supervised. The chosen 20 pig livers weighed between 460 and 590gm. The procedure was authorized and assisted by a veterinarian. After slaughtering procedures, abdominal bowels and thoracic bowels were taken out of the pig carcasses according to the slaughterhouse's usual procedure. The bowels were then taken to the swine operation theater, where surgery was performed. The portal vein was dissected close to the head of the pancreas, the infrahepatic vena cava was dissected close to the renal veins mouth, and the lower vena cava thoracic portion was dissected close to the right atrium. These veins were catheterized with a polyethylene probe N. 16, and the bowels and surrounding structures were then separated from the liver. The catheters were perfused with one L physiologic solution containing heparin (15,000 IU) for removal of clots in the veins. After that, the veins were injected with a methyl methacrylate solution (JET® solution). The solution is available in powder and liquid forms and was prepared in 1:1 proportion, and to which red spray paint was added for the portal vein, and blue paint for the vena cava. The acrylic hardened after one hour. The liver was then dipped into chloride acid 35% for 72 hours for parenchyma corrosion. After this time, these parts were washed under running water.

Variables studied

The models were evaluated according to the origin, number, and distribution of portal vein branches. Portal vein was the reference for segmentation, and hepatic veins were reference for sectorization. Hepatic and portal veins were correlated to lobation and to their functional and embryological division.

VR Model Image Generation

To generate the VR model, an acrylic model of the pig hepatic and portal veins, pictures of this model, pictures of pig liver, a personal computer, and a three-dimensional (3D) graphic software (3D Studio Max 3.0) wer used. First of all the models of pig hepatic venous system obtained as previously described were photographed to become the basis for generating images by rendering (A) and by orbital animation (B) processes.

A) For the rendering process, firstly a line was drawn above the photographic image of one of the acrylic models, following the outline from the portal vein trunk up to its distal portion of segment III branch. A line of dots had to be drawn along the outline to be rendered for vein curves and caliber definition. This initial image was the basis to which the additional branches were attached, according to the original photographic image. The branches were moved forward and backward in order to obtain the three-dimensionality of the actual model. The process was repeated to generate hepatic veins and retrohepatic vena cava images, so that both images could be brought together later on. After that, a virtual image of the pig liver parenchyma was generated to enclose both images so as to match the photographic images of the real-life organ. The parenchyma image obtained is semitransparent, so as to facilitate observation of the external structure of the organ and of its venous system simultaneously. After that, a semitransparent image of a pig through which the parenchyma image can be seen was created. Thus, two groups of composite images were obtained in this process: the first one containing images of portal and hepatic veins, retrohepatic vena cava, and hepatic parenchyma; the second one containing pig and hepatic parenchyma images.

B) For animation generation, images of orbital motion were generated through the software tool "camera", first around the first group of images, and then around the second one. Subsequently these images were placed together in the same screen for image rotation synchronization. The first group was placed in the foreground, and the second group in the background at the screen top left corner.

RESULTS

Pig liver portal vein follows an oblique caudal-cranial path from right to left, branching out to eight distinct segments. Ventral branches to the right for segments VI, VII, V and VIII (S-VI, S-VII, S-V and S-VIII), ventral branches to the left for segments II, III and IV (S-II, S-III and S-IV) in that order, and dorsal branches to both left and right for segment I (S-I) were observed according to pig liver functional and embryological division (Cantlie's line).

Five main hepatic veins and right and left accessory veins were observed. The main hepatic veins were named as follows: left hepatic vein (LHV), left middle hepatic vein (LMHV), middle hepatic vein (MHV), right middle hepatic vein (RMHV) and right hepatic vein (RHV). Main hepatic veins had two main drainage sites always on the upper third of the retrohepatic vena cava: a caudal one to the right, which presents RHV, RMHV and right accessory veins confluence, and a cranial one to the left, which presents LHV, LMHV. MHV and left accessory vein confluence.

Six venous sectors were observed: right venous sector (RVS), left venous sector (LVS), middle left venous sector (LMVS), middle venous sector (MVS), middle right venous sector (RMVS) and caudate lobe venous sector (CLVS). Correlation between hepatic veins and venous sectors was constant.

1) Pig liver segmentation: Segmentation was based on portal vein branching, as shown in Figures 1 and 2.

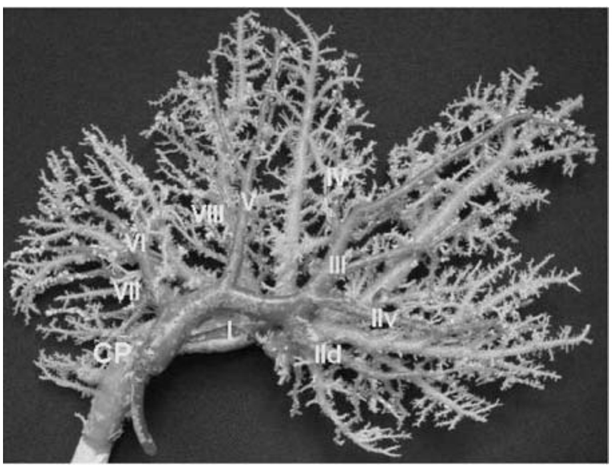

FIGURE 1 - Picture of pig liver model – hepatic segmentation.

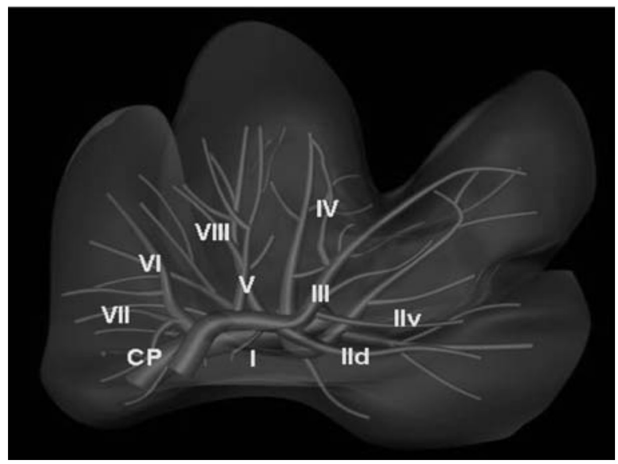

FIGURE 2 - Virtual Image of pig liver – hepatic segmentation.

– S-I corresponds to caudate lobe. Drainage by narrow caliber branches was observed of which one constituted a main trunk in 14 observations (70%) and two trunks in six observations (30%). Branches origin always occurred in the portal vein dorsal region as follows: in 12 observations (60%) in the proximal third, and in 8 observations (40%) in the distal third. Caudate process showed drainage by various narrow caliber branches, with one main trunk deriving from segment VII branch in 16 observations (80%), or it was the first branch to the right of the portal vein in 4 observations (20%);

– S-II corresponds to left lobe. Drainage by three branches in 11 observations (55%), by two branches in 7 observations (35%), and by one branch in 2 observations (10%) was observed. Branches originated in the portal vein distal third showed 100% frequency. S-II could be subdivided into dorsal and ventral when drainage occurred by two branches, and in medial and ventral when draind by yhree branches;

– S-III corresponds to left middle lobe. It is drained by one branch in 100% of the observations. Origin occurred on portal vein distal third;

– S-IV corresponds to caudate lobe. It is located in the left dorsal portion of the right middle lobe. In 20 observations (100%) one or two branches originated in the proximal third of branch III were observed. Out of these one branch occurred in 16 observations (80%), and two branches occurred in 4 observations (20%). A third branch derived from the portal vein distal third was observed to drain S-IV in 4 observations (20%);

– S-V corresponds to the ventral left portion of the right middle lobe, and drainage by one branch in 18 observations (90%), and by two branches in 2 observations (10%) was evidenced. Branches origin occurred in the distal middle third of the portal vein in 14 observations (70%), and in the proximal third in 6 observations (30%);

– S-VI corresponds to the ventral portion of the right lobe, and drainage by one branch in 18 observations (90%), and by two branches in 2 observations (10%) was observed. Branches origin occurred as a single trunk with S-VII branch. When it presented two branches, the more ventral one derived from the portal vein proximal third;

– S-VII corresponds to the dorsal branch of the right lobe, which is drained by one branch originated from a single trunk with S-VI branch in 20 observations (100%);

– S-VIII corresponds to quadrate lobe, located at the dorsal right portion of the right middle lobe, which is drained by one branch in 17 observations (85%), and by two branches in 3 observations (15%). Branches originated from S-V in 14 observations (70%), and from proximal portal vein in 6 observations (30%).

2) Pig liver venous drainage sectors: Sectorization was related to venous hepatic drainage, as shown in Figures 3 and 4.

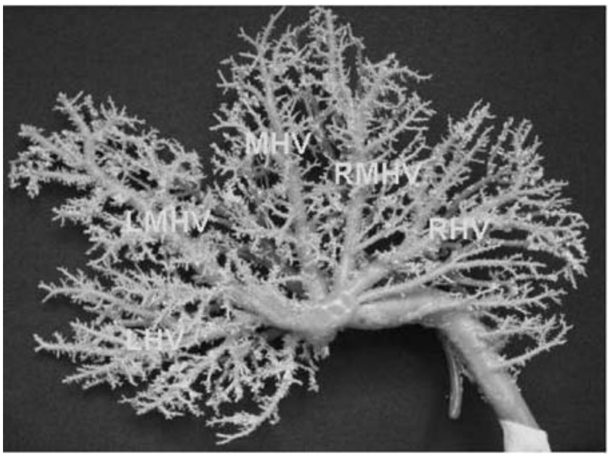

FIGURE 3 – Picture of pig liver model - hepatic veins.

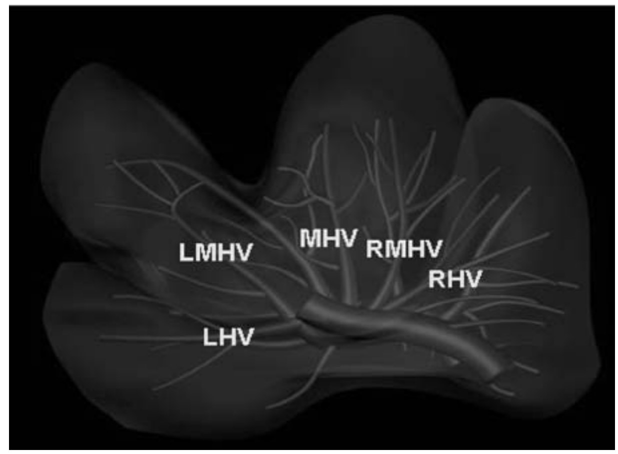

FIGURE 4 - Virtual image of pig liver – hepatic veins.

– LVS is drained by LHV, and corresponds to left lobe. We observed one accessory left dorsal vein flowing directly into vena cava in 9 observations (45%), and to LHV in 11 observations (55%);

– RVS is drained by RHV and accessory right hepatic veins, and corresponds to right lobe. One accessory vein was observed in 8 observations (40%), and two accessory veins in 12 observations (60%). Accessory veins drain S-VII only.

– MVS is drained by MHV, and corresponds to the left portion of right middle lobe;

– RMVS is drained by RMHV, and corresponds to the right portion of the right middle hepatic lobe;

– LMVS is drained by LMHV, and corresponds to left middle lobe. LMHV flowed into LHV in 13 observations (65%), and into vena cava in 7 observations (35%);

– CLVS is drained by various narrow caliber branches which flow directly into the retrohepatic vena cava along its entire path. In the pig, the retrohepatic vena cava is intrahepatic, and corresponds to the caudate lobe.

3) Pig liver and its venous system image animation: (Figure 5)

The pig was depicted with the respective topographical location of its liver. The animal is shown upside down because this is the operation position for laparotomy. The animated version allows for observation of the correlation of hepatic and portal veins with hepatic parenchyma, and of the parenchyma with the pig.

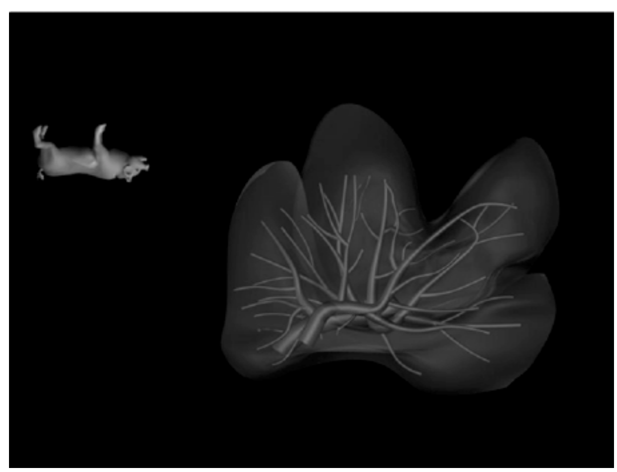

FIGURE 5 – Animated image in the web version.

DISCUSSION

From the embryological, the morphological, and the functional points of view, the Cantlie line divides human liver in right and left lobes, considering portal vein division as a two-branch bifurcation: the right branch being addressed to the right lobes, the caudate lobe right portion, and to the caudate process; and the left branch being addressed to the left and the middle lobes, and to the left portion of the caudate lobe.

Differently, portal vein bifurcation was not found in the pig as in humans, but portal vein trunk branching out the to right lobe, to the right and dorsal-left portions of the right middle lobe, and to the right portion of the caudate lobe, the caudate process here included, and the distal branches to the left lobe, to the left middle lobe, to the left ventral portion of the right middle lobe (quadrate lobe – S-IV), and to the left portion of the caudate lobe along the portal vein.

As described by BOULOGNE[15], the branch to S-V (and to S-VIII) could be found in the right portion of portal fissure, although it apparently originates from the left portal vein, if we consider the pig portal vein to be bifurcated. This author has studied pig liver segmentation in 50 portal and hepatic vein models, and used neoprene latex for injection and chloride acid for corrosion. In his study, 7 hepatic segments were described, based on the description by COUINAUD[1], at the time he had not observed S-VIII yet. BOULOGNE[15] described the right lobe as having S-VI only, and the caudate process as corresponding to S-VII.

In a subsequent study of pig hepatic segmentation in 25 portal and hepativc vein models obtained by injection and corrosion methodology, VAN MINH[11] described nine hepatic segments by dividing the right lobe into two segments, S-VI and S-VII, and described the caudate process as segment IX.

In our study models, as well as the in the study by VAN MINH[11], S-VI and S-VII could be observed in the right lobe, where S-VIII could also be observed, e. g., eight hepatic segments, just like in a more recent human liver description by BISMUTH[17] and COUINAUD[18], considering that the identification of the branch to S-VIII was always possible, although it presented narrow caliber in some cases. The fact that caudate lobe and caudate process form late around the retrohepatic vena cava, corresponding to S-I, should be emphasized.

As to pig hepatic veins, BONADEO[13] described three: RHV, MHV and LHV, from 45 models obtained by injection and corrosion methodology. He also observed one branch on the RHV right border, and two branches that flow together to form LHV. These branches were named LHV proper and LMHV. On the other hand, BOULOGNE[15] had earlier described five hepatic veins so-called "intrasegmental" veins, flowing together to the vena cava through right and left drainage systems.

Our observations are similar to those described by BOULOGNE[15]. However, a nomenclature proposal for hepatic veins has been presented with basis on the embryological origin of these veins, and on the observation of the drainage sectors as well.

The stability of pig hepatic vein number and location is probably due to pig liver embryological development proper. As reported by BOULOGNE[15], pig hepatic veins develop from right and left vitelline and umbilical veins, forming four early hepatic lobes. Right extrahepatic umbilical vein retrogresses, and early right middle lobe develop freely. On the other hand, the left umbilical vein persists until birth, and hepatic proliferation on both vein sides originates the umbilical fissure that divides early left middle lobe into a left portion (left middle lobe), and a right portion, entirely fused to early right middle lobe, which eventually forms the right middle lobe.

Such observation results could therefore explain the existence of two hepatic veins in the right middle lobe: RMHV, which drains to the right according to its origin (right umbilical vein), and MHV, which drains to the left also according to its origin (left umbilical vein). It also explains why the branch of segment IV is located in the right middle lobe, and is also a branch of segment III, which is located in left middle lobe. In addition to that, it would explain why the number of venous drainage sectors is different from the number of segments in a way that the right middle lobe presented three segments and two venous drainage sectors, and the right lobe presented two segments and one venous drainage sector.

The generation of a virtual model is due to observation of virtual reality use in medical education, surgery practice[19,20], and human anatomy teaching[21,22]. The advantage of using virtual models for anatomy studies is manyfold: low cost, unlimited time use, and most iportantly models do not deteriorate.

The development of pig liver VR animation was devised to illustrate and to contribute to the teaching of this specific anatomy. However, anatomy VR images applied to medical education are not intended to replace, but to reduce the number of cadavers[23] and animals used in the learning process, as well as to introduce another learning tool.

CONCLUSION

Pig liver segmentation and sectorization were stable in eight segments and in six venous drainage sectors.

Pig portal vein does not present right and left bifurcation, but branches addressed to right and left functional lobes.

Because of 3D visualization, semitransparency for overlapping images, and motion, pig liver VR images allow for correlatation of hepatic parenchyma with pig liver venous system, and for observation from several points of view.

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RESUMO - Objetivo: Determinar a setorização e a segmentação do fígado do suíno da raça Landrace, apresentando a sua relação com a veia porta e com as veias hepáticas, e desenvolver uma animação em realidade virtual. **Métodos:** Foram obtidos 20 moldes por meio de injeção de uma solução de metil metacrílico nas veias hepáticas e porta, e corrosão do parênquima hepático com ácido clorídrico a 35%. Um desses moldes serviu como base para se desenvolver uma animação em realidade virtual do órgão utilizando-se o programa de computação gráfica 3D Studio Max. **Resultados:** Observou-se a presença constante de oito segmentos e seis setores de drenagem venosa. Não se constatou uma bifurcação na veia porta do suíno. As veias hepáticas foram nomeadas com base na origem embriológica. Por meio da animação obtida, estabeleceu-se a relação entre o sistema venoso e o parênquima hepático. **Conclusões:** Os moldes permitiram o estudo dos setores e dos segmentos hepáticos do suíno, com a proposição de uma nomenclatura das veias hepáticas. Além disso, possibilitaram o desenvolvimento de um molde em realidade virtual, cuja animação mostra a relação do parênquima hepático com o sistema venoso do fígado do suíno e a sua observação por vários ângulos.

DESCRITORES - Anatomia comparativa. Fígado. Suíno. Realidade virtual.

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