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Experimental Swine Model for Living Donor Liver Transplantation: Introducing a Novel Liver Segmentation Method

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Abstract

Experimental Swine Model for Living Donor Liver Transplantation: Introducing a Novel Liver Segmentation Method

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Background: Living-donor liver transplantation (LDLT) is one of the most technically demanding and complicated procedures. However, unlike deceased donor liver transplantation, there is no suitable animal model for practicing LDLT. Herein, we propose a new liver segmentation method and a feasible pig LDLT model for practicing for LDLT in humans.

Methods: Four landrace pigs weighing 25, 25, 27, and 28 kg were

used as donors and recipients to establish a partial liver transplantation model. Partial liver transplantation was performed using a right liver and a left liver, respectively, based on a new segmentation system compatible with that of humans.

Results: We established a new segmentation system for porcine liver transplantation and a partial liver transplantation model. For right liver transplantation, 91 and 142 minutes were required to operate on the donor and recipient, respectively; for left liver transplantation, 57 and 104 minutes were required to operate on the donor and recipient, respectively. All pigs that underwent partial liver transplantation remained alive until the operation was completed.

Conclusion: It is expected that this new pig model based on the new segmentation system will be suitable as an educational tool for LDLT training and will replace the existing animal models for partial liver transplantation.

Keywords: liver transplantation, animal model, liver segmentation, living donor

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1. Introduction

Partial liver transplantation (PLT), including both living donor and deceased donor split or reduced transplantation, is a good alternative to solve graft size mismatch in whole-liver transplantation (WLT) for small-sized patients. However, in PLT, especially in living-donor liver transplantation (LDLT), considerable experience is required because of the risk of postoperative complications, including mortality or morbidity in healthy donors[1], biliary problems[2], and the difficulty of surgical methods. Therefore, experienced surgeons perform transplantation procedures in most transplantation centers. However, it is necessary to establish a well-designed training program for young doctors who want to enter this field, as the operation time and complication rate tend to increase before they achieve competence in this procedure[3]. It is also feasible to teach basic techniques such as vascular anastomosis using animal tissue in a dry laboratory[4]. However, during liver transplantation, there is a high possibility that vital signs become unstable in the anhepatic phase and during reperfusion; therefore, in vivo experiments are essential for novices. As for now, this animal experiment was performed by experienced surgeons and was focused on making a replaceable animal practice model for human living donor liver transplantation; therefore, learning curve and reproducibility could be another topic to deal with later on when an experiment is performed by novices using this training model.

Many reports on animal models exist for WLT because

animal-based WLT models are very similar to those of humans. However, regarding animal models for PLT, it is difficult to find reports that describe technical procedures, although there have been several reports of PLT models using mice[5,6]. Animals used in liver transplantation models must be large enough to be comparable to humans, be inexpensive to allow for performance of large numbers of experiments, and have an anatomical structure similar to that of humans. To meet all the conditions, we chose the pig, which is known to be one of the most widely used animals (other than rodents) and the most appropriate animal for PLT models[7].

However, an animal model that simulates PLT in humans has not been reported due to anatomical differences, such as an inseparable inferior vena cava (IVC) encircled by the liver parenchyma in pigs and primates[8,9]. Therefore, in this study, we aimed to understand the anatomical differences between pigs and humans and establish a feasible liver transplantation model that simulates PLT in humans.

2. Materials and methods

All experiments were approved by the Institutional Animal Care and Use Committee of Seoul National University Hospital (SNUH-IACUC). The animals were kept in our in-house facility, which is AAALAC International accredited in accordance with the Guide for the Care and Use of Laboratory Animals, 8th Edition, NRC (2010). The operation was performed at the Biomedical Research Institute of Seoul National University Hospital, which met the

international standards for animal testing.

To proceed with PLT using pigs, it is necessary to first understand the anatomical structure of pigs that is comparable to that of humans. The previous liver nomenclature for pigs was inappropriate because it seemed not to be classified based on the Glissonian pedicle approach, but only on gross appearance[8-10]. Therefore, we redefined the liver anatomy of pigs using the Glissonian pedicle approach or detailed dissection of hilar structures in several preliminary experiments and in this study (Figure 1 and 2)[11]. The generic terms for liver segmentation in pigs are also different from those in humans. In this study, all terms were described in compatible human anatomical terms using the Brisbane terminology [12,13]. The previous anatomical terms used for pigs are attached for comparison.

Right liver graft and left liver graft transplantations were performed separately in landrace pigs. The weight of the pigs for right liver graft transplantation was 25 and 27 kg for the donor and recipient, respectively, and 25 and 28 kg for the donor and recipient, respectively, for left liver graft transplantation. Before anesthesia, 5 mg/kg of zoletil and 2 mg/kg of xylazine were injected intramuscularly as sedative agents. Subsequently, 2% isoflurane was administered (inhalational anesthesia), and 0.1 mg/kg of vecuronium was used as a muscle relaxant. To relieve stress during the operation, steroids were not administered intravenously. During the recipient hepatectomy, to prevent cardiac arrest, systemic circulation

was maintained via portocaval shunt and additional anesthesiologic medication was not administered to increase blood pressure. One operator and two assistants participated in the surgery, and a scrub nurse and veterinarian assisted with the operation and anesthesia.

3. Results

3.1 New porcine liver anatomy using terminology compatible with that used for humans

Porcine liver is reclassified based on the human nomenclature system. Figure 1 shows the gross appearance of the porcine liver, which is annotated using conventional nomenclature based on surface anatomy (A) and comparable human anatomical terms referring to Brisbane terminology[12,13](B). Table 1 shows the anatomical similarities and differences between pigs and humans.

1. The right anterior and right posterior portal veins(RPPVs) branch off separately without sharing a common trunk (right portal vein)[9,10] , which can be found in type III portal vein variations in humans[14] (Figure 2 [A]).
2. The structures of the hepatic artery (Figure 2 [B]) and bile duct (Figure 2 [C]) are not much different from those of humans.
3. There are four hepatic veins corresponding to each of the four lobes in the pig liver, among which the right medial lobe has an extra hepatic vein (the middle hepatic vein [MHV]) along the

Midplane of the Liver, resulting in a total of five hepatic veins[9]. However, just before the hepatic vein-IVC confluence, the pig's hepatic veins form the right hepatic vein (RHV) and MHV+left hepatic vein (LHV) trunk, as observed in the human liver[15] (Figure 2 [D]).

4. The caudate lobe of the pig liver encircles the IVC; therefore, it is difficult to detach it from the IVC[8,9].

3.2 Partial liver transplantation model

3.2.1. Donor retrieval

1) Common procedure

a. Incision: A long midline incision is made in advance, followed by an additional transverse incision.

b. Liver mobilization: Unlike humans, pigs have very little bare area, so it is sufficient to flip the right liver, peel off the peritoneum surrounding the IVC, and remove some of the suprahepatic IVC.

c. Cholecystectomy: Since the cystic artery and cystic duct are thin and long, they are tied together and the gallbladder is removed.

2) Right partial liver graft

a. Hilar dissection: In pigs, the RPPV and right anterior portal vein (RAPV) separately branch from the main portal vein (MPV); therefore, RPPV and RAPV are dissected and isolated individually (Figure 3 [A]).

b. Hilar dissection: After dissecting and separating the common bile duct (CBD), the right hepatic artery (RHA) located behind the CBD is isolated (Figure 3 [B]).

c. Midplane demarcation: After clamping the RHA, RAPV, and RPPV temporarily, the demarcation line of the Midplane is identified and marked using a Bovie (Figure 3 [C]).

d. Parenchymal dissection in the lower two-thirds of the Midplane of the Liver: a cavitron ultrasonic surgical aspirator (CUSA) is used to perform parenchymal dissection along the pre-marked demarcation line. The MHV from the graft is excluded (Figure 3 [E]).

e. Bile duct division: After dissecting the hilar plate, the confluence of the right hepatic duct (RHD) and left hepatic duct (LHD) is determined by probing through the cystic duct, and the RHD is transected near the confluence.

f. Parenchymal dissection of the remaining upper part of the Midplane of the Liver: The IVC is attached to the right liver (graft) during procurement because the pig's IVC is attached to the parenchyma.

g. Hanging maneuver (optional): As in humans, the hanging maneuver can be performed in pigs. A route to the left side of the IVC is created by tunneling through the parenchyma between the MHV and RHV and then a Nelaton catheter is placed through it. Due to the risk of

bleeding, this is not mandatory.

h. Graft extraction: After parenchymal dissection, the RHA is divided first. Next, the starting points of the left portal vein (LPV) and MPV are individually divided to obtain one portal vein (PV) opening. It is assumed that the MPV is the RPV for implantation. Separate division of RPPV and RAPV can be considered if practice for venoplasty, such as a Y-graft, is required. After that, at the level of RHV insertion, the IVC is divided excluding the common trunk of the MHV and LHV as shown in Figure 3 (F).

i. Graft extraction: Finally, after dividing the infrahepatic IVC using a gastrointestinal anastomosis (GIA) stapler, the right liver graft including the IVC is extracted [Figure 4 (A)].

3) Left partial liver graft

a. Hilar dissection: The left lateral border of the hepatoduodenal ligament is dissected to isolate the LHA and LPV (Figure 3 [A] and [B]).

b. Midplane demarcation: After clamping the LHA and LPV temporarily, the demarcation line of the Midplane is identified and marked using electrocautery (Figure 3 [D]).

c. Parenchymal dissection: CUSA is used to perform parenchymal dissection along the pre-marked demarcation line. The MHV is included in the graft (Figure 3 [E]).

d. Bile duct division: After dissecting the hilar plate, the confluence of the RHD and LHD is determined by probing through the cystic duct, and the LHD is transected near the confluence.

e. Hanging maneuver: As in right graft PLT, the hanging maneuver can be performed. A route is created to the left side of the IVC by tunneling through the parenchyma between the MHV and RHV and then a Nelaton catheter is placed through it.

f. Graft extraction: After parenchymal dissection, the LHA and LPV are divided. Finally, MHV+LHV is divided at their confluence into the IVC (Figure 4 [B]).

3.3 Recipient hepatectomy and graft implantation model

3.3.1. Recipient hepatectomy (Figure 5)

a. Incision: A long midline incision and an additional transverse incision are made.

b. Liver mobilization Liver mobilization is performed in the same manner as in the donor operation.

c. Hilar dissection: The CBD is isolated (Figure 5 [A]) and transected at the proximal part as close to the hilum as possible.

d. Hilar dissection: After identifying the proper hepatic artery (PHA), it is clamped and the RHA and LHA are divided

(Figure 5 [B]). Prophylactic heparin is administered through the hepatic artery (HA) to prevent thrombosis.

e. Hilar dissection: Isolate and transect the RAPV, RPPV, and LPV as far as possible from the proximal part of the MPV (Figure 5 [C]). Trim them to create a common trunk for anastomosis.

f. Temporary portocaval shunt: To prevent bowel congestion and hypovolemic shock from disruption of portal venous blood flow, a temporary portocaval shunt is created between the PV and infrahepatic IVC (Figure 5 [D]).

g. Isolating the IVC: Unlike in humans, the hepatic parenchyma of pigs is not separate from the IVC; therefore, a GIA stapler is used to remove the parenchyma from the IVC (Figure 5 [E]). For right graft PLT, the parenchyma of the right lateral lobe (RLL) is removed using a GIA stapler along the right border of the IVC (Figure 5 [F]). After the HV of the right medial lobe (RML) is isolated and clamped for HV anastomosis (Figure 5 [H]), the remnant hepatic parenchyma is removed using a GIA stapler (Figure 5 [I]). For left graft PLT, the MHV+LHV is saved instead.

3.3.2. Graft implantation (Figure 6)

a. Hepatic vein anastomosis: Both suprahepatic and infrahepatic IVC are clamped completely (Figure 6 [A]), and anastomosis is performed by continuous suturing using 6-0 prolene suture

between the suprahepatic IVC of the right graft (MHV+LHV in left graft PLT) and the HV stump (MHV+LHV stump in left graft PLT) (Figure 6 [B] and [C]). The vascular clamp is then relocated to the anastomosis to restore blood flow in the IVC.

b. Portal vein anastomosis: After transecting the temporary portocaval shunt using a TA stapler or suture ligation (Figure 6 [D]), anastomosis is performed by continuous suturing using 6-0 prolene suture between the MPV of the right graft (LPV in left graft PLT) and the MPV of the recipient (Figure 6 [E] and [F]).

c. Reperfusion: Warm saline is administered and the portal vein clamp is released to allow for reperfusion (Figure 6 [F]).

d. Hepatic artery anastomosis: The HA of the graft is first heparinized, and then it is anastomosed to the recipient's PHA (RHA or LHA could be available considering size discrepancy) by interrupted suturing using 7-0 nylon sutures (Figure 6 [G]).

e. Bile duct anastomosis: Anastomose the RHD of the graft (LHD in left graft PLT) to the recipient's CHD by continuous suturing using 6-0 prolene sutures (Figure 6 [H]).

f. Closing: Abdominal wall repair is performed after hemostasis is achieved.

3.4 Operation time

For right graft hepatectomy, operation on the donor and recipient required 91 and 142 minutes, respectively, whereas operation on the donor and recipient required 57 and 104 minutes, respectively, for left liver transplantation. Because the MHV was not reconstructed with the expanded polytetrafluoroethylene (ePTFE) vascular graft but perfusion of the graft was conducted using saline, the bench procedure only required 1 minute to complete. All recipients survived until the end of the surgery and were euthanized using potassium chloride.

4. Discussion

Laboratory animals have been extensively used in research since William Castle began breeding mice and performed a study using them in 1902[7]. Experimental animals were used for liver transplantation for the first time in 1955[16]. Since then, experiments using pigs have been performed, and pigs have been used in many transplant-related experiments because of the similarity in the anatomical structures of pigs and humans[8,9,15,17]. However, due to the difference in the structure of the liver lobes between them, many experiments have been performed in anatomical planes different from those of the human liver[18].

By casting the blood vessels and biliary tract of pigs, the shape of the PV, HA, HV, and BD can be obtained[11,19]. It has been recognized that the anatomical structure of Glissonian pedicles in pigs are very similar to that of humans[10,19]. One of the common mistakes in

comparing pig and human livers is to consider the RML as consisting of S5 and S8[9]. Based on the PV, the RML of pigs consists of S5, S8, and S4; therefore, the anatomical structure dividing the RML and left medial lobe (LML) is called the Midplane of the Liver in human anatomical terms based on Brisbane terminology[13,20]. In many studies, hepatic segmentation in pigs has been described differently from the clinical reality, and actual experiments were also performed based on incorrect segmentation[9,21].

Several studies have examined the structure of hepatic blood vessels and bile ducts in pigs[19,22]. In the anatomical structures of the porcine liver, there may be variations similar to those in humans[14,23-25]. This study focused on describing the unique anatomical features of the pig liver for the procurement of partial grafts and technical procedures for PLT. In this study, the anatomical structure was not confirmed by CT scans and MRI before surgery. However, in several experiments, it was found that most of the previous anatomical divisions of the porcine liver were inappropriate. Therefore, we redefined the anatomical structure of the porcine liver as presented in the results[12](Figure 1 and Table 1). In addition, even if there are variations, we believe that there will be no difficulty in learning the technique of liver removal and transplantation.

In this experiment, a hanging maneuver was performed using a Nelaton catheter. In humans, the hanging maneuver can be useful for an anterior approach when right liver mobilization is not easy[26]. In pigs, the IVC and the parenchyma is not separated, so the hanging

maneuver can be used to prevent the IVC damage from an unexpected event by securing space between them and help with smooth dissection between the RHV and MHV. However, it is not a mandatory technique because it can cause major bleeding in attempting the maneuver.

The structural difference between pig and human livers lies in the absence of clear separation between the IVC and the parenchyma in pigs. Consequently, forcibly dissecting the IVC and the parenchyma poses a high risk of excessive bleeding. Excessive bleeding can result in fatal outcomes during pig surgery, while excessive tissue damage hinders the core objective of achieving effective training in liver transplantation. In light of these challenges, our research presents a method for separating the parenchyma without causing damage to the IVC by utilizing multiple stapling along the adjacent region of the IVC.

Compared to the human setting, portal vein clamping with complete IVC clamping significantly reduces blood pressure in pigs. Therefore, during recipient surgery, several strategies are important, such as temporary portocaval shunt and changing from total to partial vascular clamping immediately after completion of hepatic vein anastomosis. Simultaneous closure of the PV and IVC during pig experiments can lead to cardiac arrest. Thus, it is necessary to maintain systemic circulation in anhepatic phase[17,27]. During the recipient hepatectomy, systemic circulation was maintained via portocaval shunt. Also, venovenous bypass (VVB) is necessary in

survival model[17].

During the experiment, there was not measurement of blood loss because this experiment was performed by experts. However, blood loss amount needs to be further investigated when repeated experiments are performed by novices using this pig experimental model.

The medial parts of segment 5 and 8 (S5/8) are drained by the MHV in the pig as well as in humans. Although MHV reconstruction is possible in this experimental model, it was not actually proceeded with. When performing experiments to avoid S5/8 congestion or the MHV reconstruction being required using artificial graft, an additional procedure will be able to be performed.

So far, experiments have been conducted based on the pig anatomy whose concept is described differently from that of humans. The point to be emphasized the most in this paper is Table 1. It shows a new concept of the pig anatomy corresponding to human liver anatomy based on the PV and HV anatomy, which does not use the apparent lobe as a landmark[11]. Of course, to conduct a study to assess post-transplant results (such as physiology of recipients or remnant liver function of donors) using this model, the anatomical structure of pigs must be reevaluated prior to surgery to obtain unbiased results. Furthermore, it is necessary to establish a new postoperative care protocol for the survival of pigs after transplantation.

Small-for-size syndrome (SFSS) is one of the most important side

effects of LDLT; it cannot be overlooked and occurs when the liver volume of the graft does not sufficiently meet the metabolic requirements of the recipient . Therefore, studies on SFSS in animals have also been reported[29]. However, because variables such as congestion can occur following hepatic vein ligation in humans, there is a limitation in applying the data to humans. In this case, the Seoul National University Hospital model, which guides the resection of the liver along the Midplane of the Liver, might show more accurate results. Porcine liver also ranges from 1500 - 2000 g in weight depending on the pig[30]; therefore, it can be a good model if the weight of the pig is adjusted.

According to the Nakamura's classification[31], PV variations can be categorized into five types. Type A represents a normal anatomy, while type B consists of RPPV, RAPV and LPV forming a trifurcation. Type C refers to RAPV branching outside the parenchyma, whereas type D involves RAPV branching inside the parenchyma. Type E indicates that all branches originate respectively from the MPV. In most cases, porcine PVs exhibit variations of type C or D, and the separation of the IVC from the parenchyma is very difficult. Therefore, the Rt. graft model in this study is not suitable as a survival model. If experimental studies for survival models need to be conducted, applying the left graft model would be more feasible. However, utilizing the right graft model could be beneficial for surgical practice involving Y-graft utilization or venoplasty, considering the variations in the portal vein.

As for donors, studies can be conducted to determine how much of the liver volume can be left. In general, the remnant volume of donors varies from less than 30% to 35% or more, depending on the transplant center[32-34]. We believe that this can be applied to humans through a number of studies on pig weight to graft ratio and this ratio could have an effect on the laboratory tests of blood, liver biopsy, and survival rates.

Hepatic artery occlusion, which occurs after liver transplantation surgery, is a prominent cause of unfavorable outcomes for the recipient. It is well known that hepatic artery occlusion is more likely to occur when the diameter of the artery is small[35] or when the length of the donor's artery is excessively long[36]. In the porcine liver transplantation model we have presented, donor's hepatic artery can be cut at the level of the celiac axis, gastroduodenal artery bifurcation, RHA and right anterior hepatic artery to secure arteries of various diameters and lengths. This approach enables the practice of hepatic artery anastomosis based on diameter and the refinement of the artery to an appropriate length.

Until Cantlie's proposal in 1897, it was believed that the human liver was divided into the left and right lobes solely by the falciform ligament. However, following Couinaud's introduction of a classification system based on the branches of the portal vein, the human liver gradually began to be distinguished in terms of functional classification rather than purely morphological classification. Nevertheless, despite considerable time having passed since

Couinaud's classification system was introduced, the segmentation of the pig liver continued to rely on the traditional morphological classification, inevitably resulting in disparities from reality(Table 2). Through this study, we anticipate widespread application of the novel functional classification system we have proposed, particularly in animal experimentation involving pigs.

4.1 Conclusion

The anatomical structure of porcine liver is very similar to that of humans; therefore, the same classification of the structure of blood vessels and bile ducts can be applied to both. However, the new nomenclature that is comparable with that of humans and the new pig model we suggest for PLT is expected to be suitable as an educational tool for LDLT.

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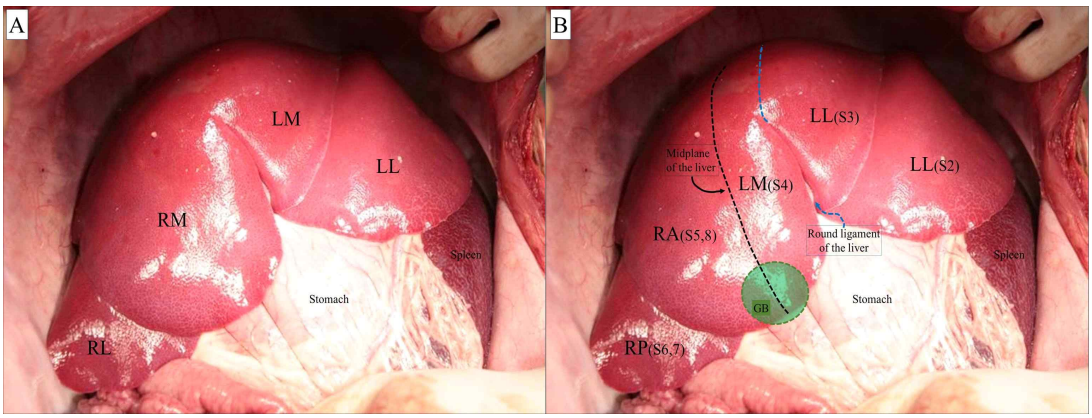
Table 1. Anatomical differences between pig and human

Pig	Human	Couinaud classification
Rt. lat. lobe	Rt. post. section	S6 + S7
Rt. med. lobe	Rt. ant. section + Lt. med. section	S4 + S5 + S8
Lt. med. lobe	Lt. lat. section	S3
Lt. lat. lobe	Lt. lat. section	S2
Caudate lobe	Caudate lobe	S1
Post. vena cava	Inf. vena cava	

Table 2. Comparison of chronology in liver segmentation between human vs. pig

Time point	before 1897	1897(Cantlie)	1957(Couinaud)	2000(Brisbane)	2023(This study)
Human	Morphological segmentation	Functional segmentation			
Plane dividing right and left liver	Falciform ligament	Cantlie's line	between S5/8 and S4	Midplane of the liver (between right anterior section and left medial section)	
Pig	Morphological segmentation				Functional segmentation
Plane dividing right and left liver	Morphologic division between right medial lobe and left medial lobe				New plane defined by inflow located in the right medial lobe

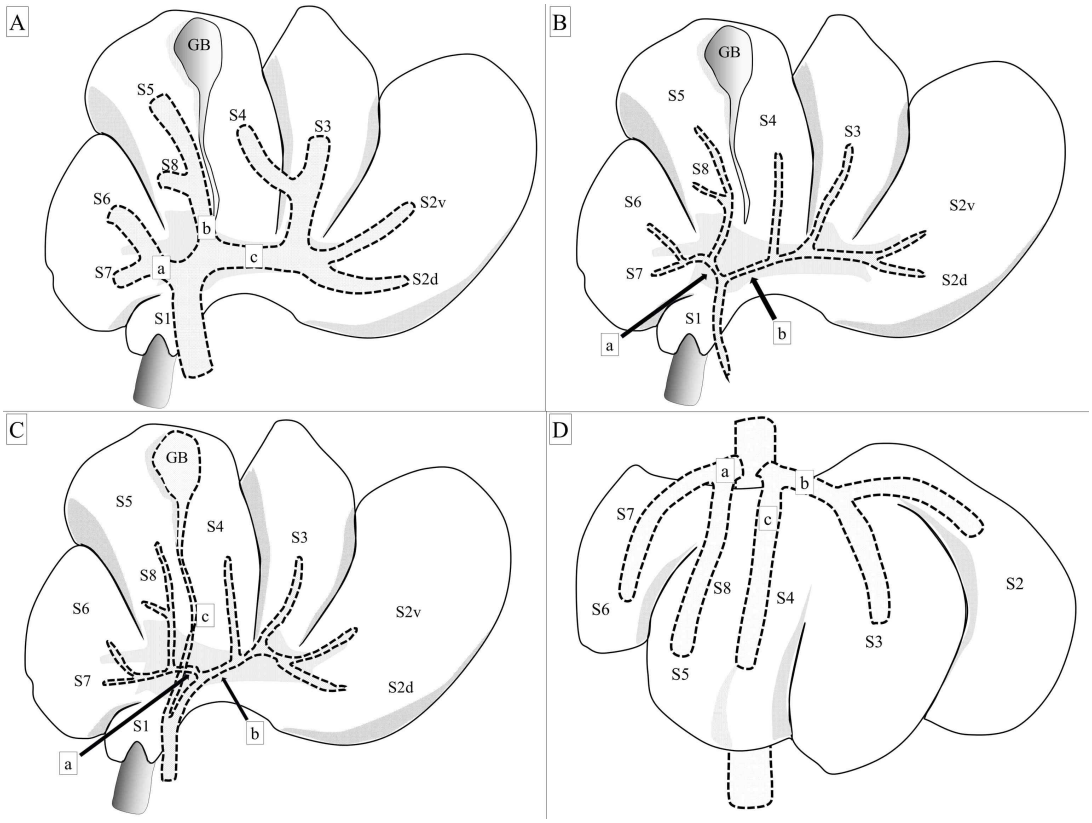
Figure 1. Liver anatomy of a pig



A) Gross appearance of the porcine liver (annotated with conventional nomenclature based on surface anatomy)

B) Porcine liver annotated with human anatomical terms based on Brisbane terminology

Figure 2. Vascular and biliary anatomy of the porcine liver



A) Portal vein anatomy

a: right posterior portal vein, b: right anterior portal vein, c: left portal vein

B) Hepatic artery anatomy

a: right hepatic artery, b: left hepatic artery

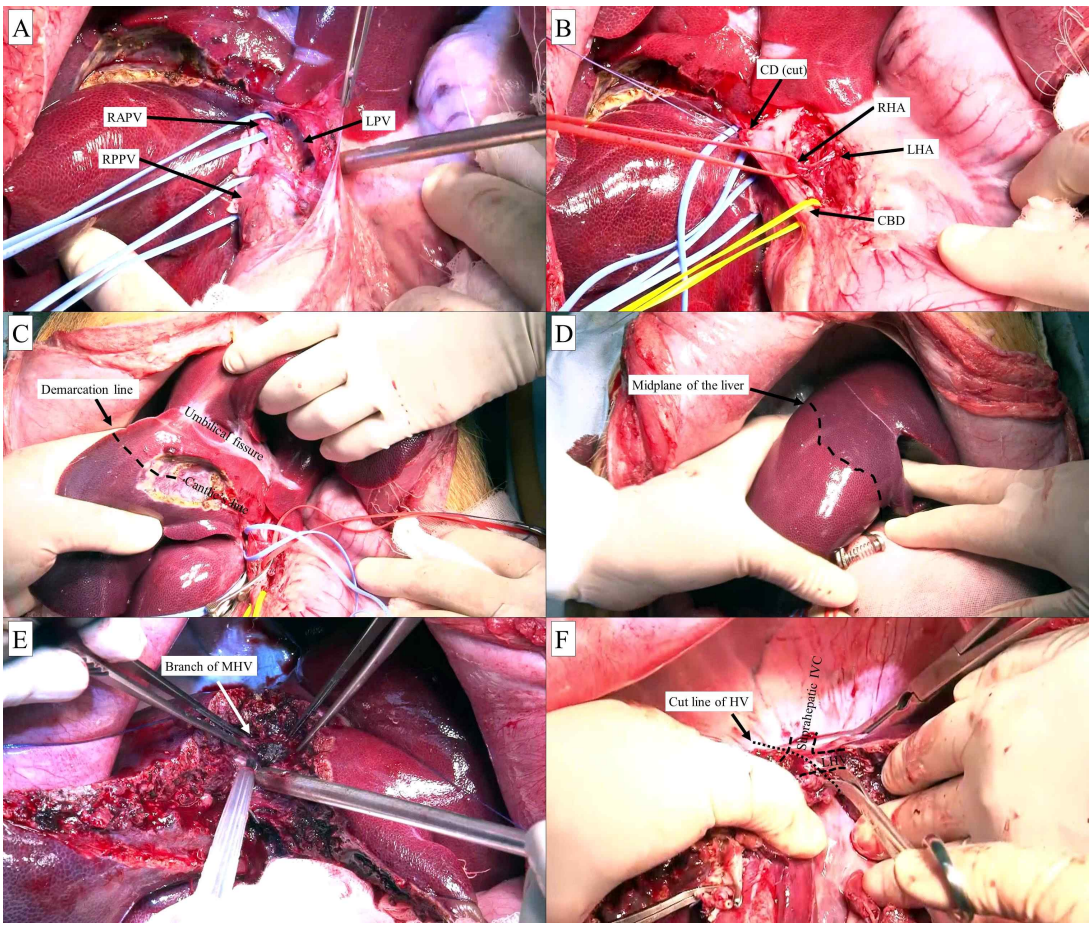
C) Bile duct anatomy

a: right hepatic duct, b: left hepatic duct, c: cystic duct

D) Hepatic vein anatomy

a: right hepatic vein, b: left hepatic vein, c: middle hepatic vein

Figure 3. Hilar anatomy and demarcation line



A) Hilar dissection

B) Hilar dissection

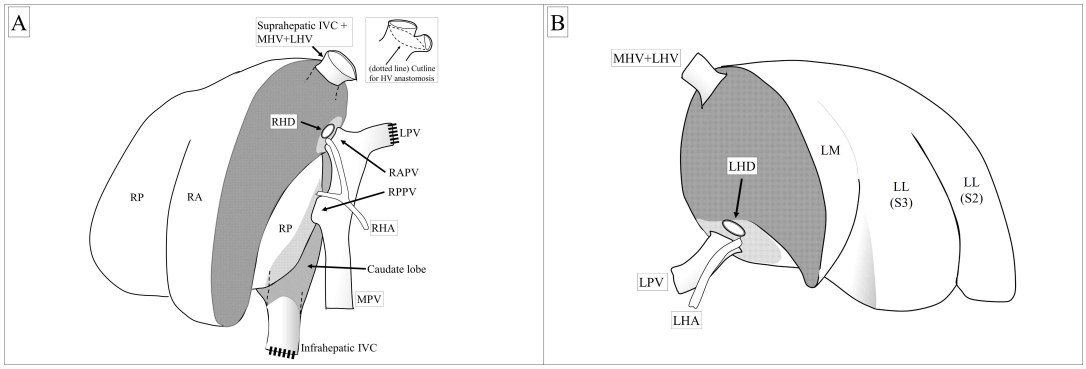
C) Midplane demarcation after temporary clamping of the right hepatic artery, right anterior portal vein and right posterior portal vein

D) Midplane demarcation after temporary clamping of the left hepatic artery and left portal vein

E) Parenchyma dissection

F) Hepatic vein division

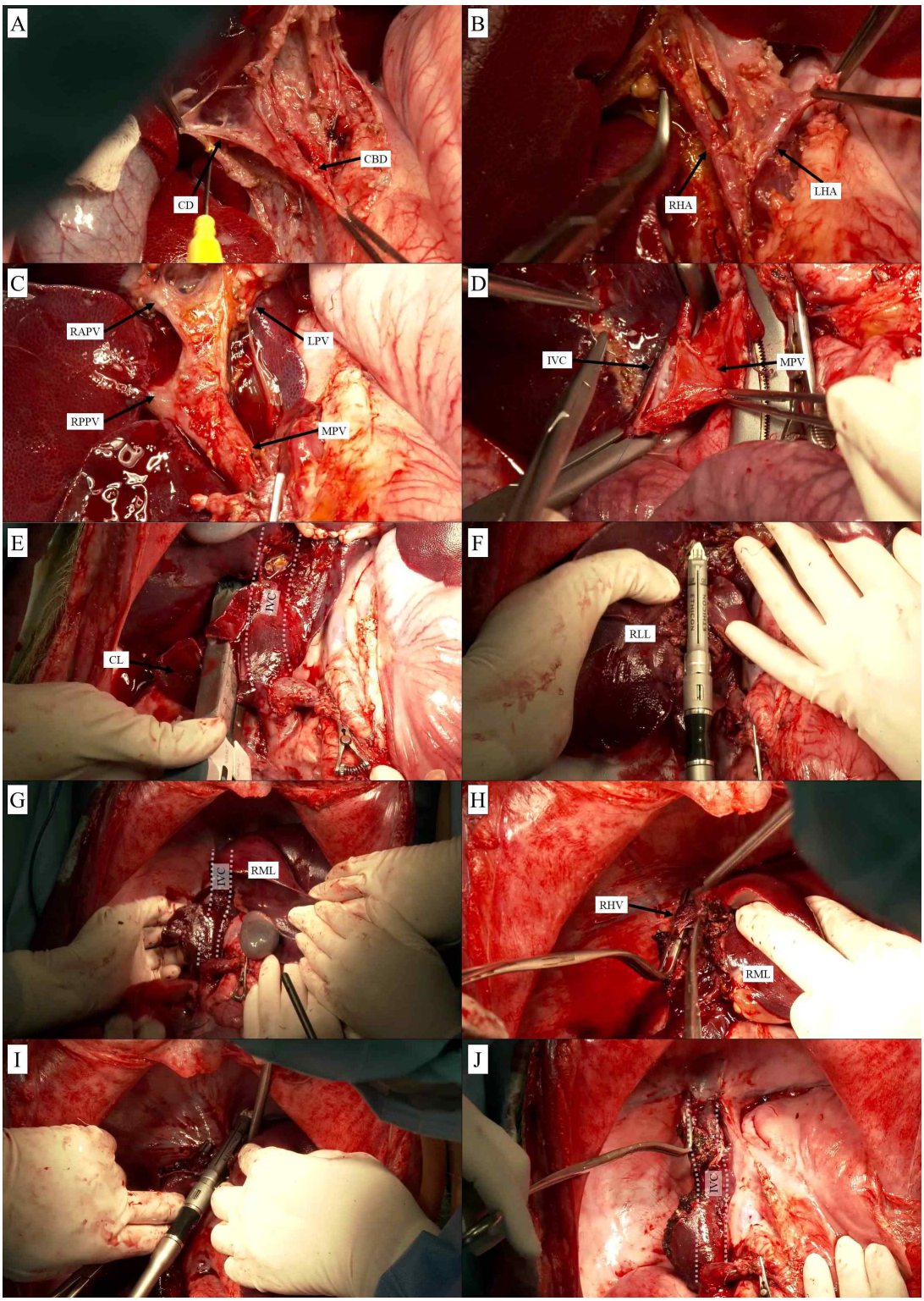
Figure 4. Hemi-liver graft



A) Right liver graft

B) Left liver graft

Figure 5. Recipient hepatectomy



A) Cystic duct and common bile duct

B) Hepatic artery

C) Portal vein

D) Temporary portocaval shunt formation

E) Removing the parenchyma along the right border of the inferior vena cava (IVC) (caudate lobe)

F) Removing the parenchyma along the right border of the IVC (right lateral lobe [RLL])

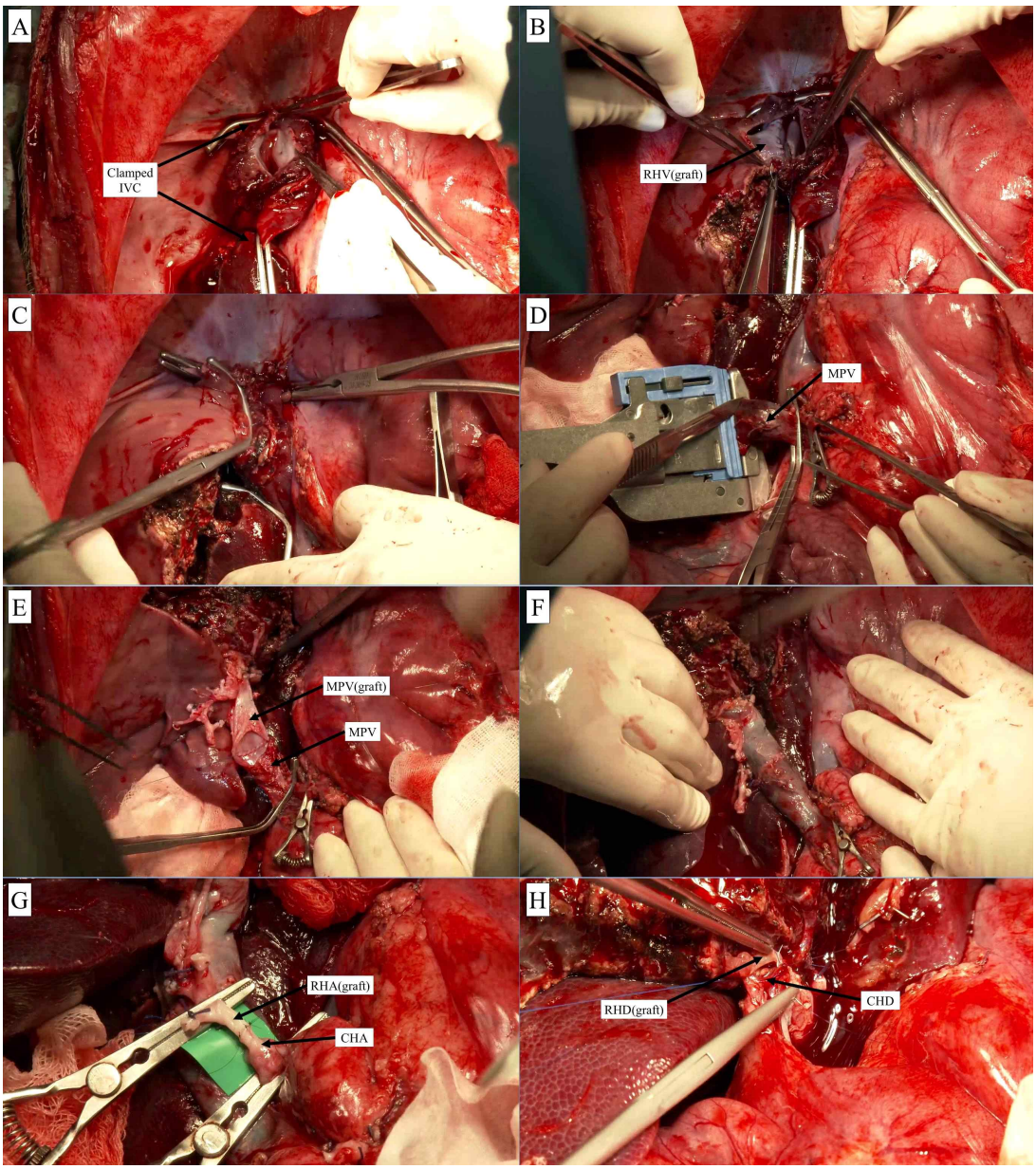
G) Contour of the right side of the IVC after removing the RLL

H) Clamping the right hepatic vein for hepatic vein anastomosis

I) Completing hepatectomy (right medial lobe + left medial lobe + left lateral lobe)

J) Completed recipient hepatectomy

Figure 6. Graft implantation



A) Total clamping of the inferior vena cava (IVC) and trimming of the right hepatic vein (RHV) for anastomosis

B) Hepatic vein anastomosis

C) Partial clamping of the RHV and releasing of IVC clamping

D) Ligation of temporary portocaval shunt

E) Portal vein anastomosis

F) Warming and reperfusion

G) Hepatic artery anastomosis

H) Bile duct anastomosis

국문초록

서론: 생체간이식은 많은 기술이 요구되는 복잡한 술기이다. 하지만 뇌사자 간이식과는 다르게 생체간이식을 연습할 수 있는 적합한 동물실험 모델은 전무한 실정이다. 그래서 우리는 새로운 돼지 간분절 분류법을 제시하고 그에 걸맞은 생체간이식 연습 모델을 만들고자 한다.

방법: 두 쌍의 돼지를 사용하여 각각 우간 이식편, 좌간 이식편의 기증자 수술과 수혜자 수술을 시행하였다. 이 때, 기존의 돼지 간분절 분류법과는 다른 새로운 분류법을 사용하여 인간의 생체간이식과 유사하게 실험을 진행하였다.

결과: 우간 이식편을 사용한 수술에서는 기증자 및 수혜자의 수술시간이 각각 91분, 142분이 소요되었다. 그리고 좌간 이식편에서는 각각 57분, 104분이 소요되었다. 모든 돼지는 수술이 끝날 때까지 살아있었다.

결론: 우리가 새롭게 제시한 돼지 간분절 분류법에 따른 생체간이식 모델은 실제 인간에서와 유사한 방법으로 생체간이식을 연습할 수 있는 좋은 대안이 될 수 있을 것으로 생각한다.

주요어: 생체간이식, 동물실험, 간분절
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