Laparoscopic left hemihepatectomy combined with right lateral hepatic lobectomy in pigs: surgical approach and comparative study of the inflammatory response versus open surgery

Hua Zhang1, Jin-Jin Tong1, Zhao-Nan Zhang1, Hong-Bin Wang2*, Yong-Hong Zhang1

1 Department of Animal Science, College of Animal Science and Technology, Beijing University of Agriculture, Beijing, China; 2 Department of Veterinary Surgery, College of Veterinary Medicine, Northeast Agricultural University, Harbin, China.

Abstract

This study describes a left hemihepatectomy combined with a right lateral hepatic lobectomy. It compares the inflammatory response associated with laparoscopic hepatectomy (LH group, n = 7) with conventional open hepatectomy (OH group, n = 7). Blood was collected before surgery as well as 1, 2, 3, 5, and 7 days after surgery to determine the white blood cell count and levels of serum cortisol (COR), interleukin-6 (IL-6), and C-reactive protein (CRP). The left hemihepatectomy combined with a right lateral hepatic lobectomy was completed in miniature pigs. The average operative time was 139.00 ± 9.07 min, which was longer than that in the OH group (121.67 ± 3.02 min). The length of surgical incision associated with the OH group was 17.93 ± 1.09 cm, significantly longer than that related to the LH group (5.10 ± 0.17 cm). The estimated mean blood loss in the LH group was 136.43 ± 63.24 mL, which was significantly lower than that in the OH group. No severe complications (e.g., massive bleeding, bile leakage, and air embolism) were reported. The CRP levels, COR, and IL-6 were reported, most of which have involved expensive instruments and procedures of varied complexity.

Studies have also shown that the serum levels of interleukin-6 (IL-6) and C-reactive protein (CRP) are lower after laparoscopic surgery than after open surgery. Conversely, some studies have shown no significant differences between two surgical approaches concerning the surgical inflammatory response as measured using cortisol (COR) levels. However, only a few previous studies on laparoscopic hepatectomy performed in veterinary surgery and the experimental animal field have been reported, most of which have involved expensive instruments and procedures of varied complexity.

Introduction

Laparoscopic hepatectomy is a standard surgical procedure performed to treat liver cancer and retrieve donor liver grafts among other techniques. In medical research and experimental studies, the porcine model of hepatectomy is a crucial research tool for evaluating new surgical methodologies, transplantation, regeneration, and medical instruments. The successful establishment of hepatectomy models can promote technological advances and develop new treatment methods for hepatic diseases.

Minimally invasive laparoscopic surgery causes minimal trauma to the abdominal wall, resulting in reduced pain and fewer wound complications, faster recovery times, and a more rapid return to activity than conventional surgery. However, only a few previous studies on laparoscopic hepatectomy performed in veterinary surgery and the experimental animal field have been reported, most of which have involved expensive instruments and procedures of varied complexity.

*Correspondence:
Hong-bin Wang, PhD
Department of Veterinary Surgery, College of Veterinary Medicine, Northeast Agricultural University, Harbin, China
E-mail: 20158601@bua.edu.cn

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License which allows users to read, copy, distribute and make derivative works for non-commercial purposes from the material, as long as the author of the original work is cited properly.
This study introduces a laparoscopic technique for a purely laparoscopic left hemihepatectomy combined with a right lateral lobectomy in pigs. Additionally, we compared the outcomes and surgical stress associated with the laparoscopic approach with those related to open surgery.

Materials and Methods

Animals. This study used 14 Bama miniature pigs with an average age of 6 months (4-8 months old) and an average bodyweight of 18.50 kg (15.80 - 23.50 kg). The pigs were randomly assigned to two groups, including the laparoscopic hepatectomy (LH) group (n = 7) and open hepatectomy (OH) group (n = 7). The Animal Ethics Committee of Northeast Agricultural University, Harbin, China approved the experimental protocol (BUAEC2019-0902). The experiments described herein comply with the People's Republic of China's existing regulations and the standards of the Institutional Animal Care and Use Committee of Northeast Agricultural University, Harbin, China.

Anesthetic protocol. Before surgery, atropine sulfate (0.05 mg kg⁻¹; Harbin Pharmaceutical Group, Harbin, China) was injected subcutaneously; then, xylazine (1.00 mg kg⁻¹; Bayer Health Care AG, Leverkusen, Germany) and ketamine hydrochloride (10.00 mg kg⁻¹; Hansen Pharma Co. Ltd., Changsha, China) were administered intramuscularly 15 min later. After the experimental pigs were sedated, propofol (5.00 mg kg⁻¹; Libang Pharma Co. Ltd., Xian, China) was slowly injected through the ear margin vein to induce anesthesia. Then, endotracheal intubation was performed with a 6.00-7.50-mm endotracheal tube under laryngoscope guidance, and anesthesia was maintained via the inhalation of 1.50 - 3.00% isoflurane (Jiupai Pharmaceutical, Jinzhou, China) using an anesthesia machine. During surgery, normal saline (3.00 mL kg⁻¹ per hr) was infused through the ear margin vein, and various physiological parameters were continuously monitored.

Surgical technique. The miniature pigs were placed in the supine position and secured on the operating table, tilted to 10-30° with the head placed more elevated than the tail. The anterior abdomen was shaved, disinfected, and draped for laparoscopic surgery. A Veress needle was used to create an artificial pneumoperitoneum by filling the abdominal cavity with CO₂ (12.00 mm Hg). Four trocars were used for this procedure. One trocar (portal A) was used to place the laparoscope, and the other three (portals B, C, and D) were used for surgical instrument access (Fig. 1).

First, scissors were used to divide the round ligament, sacral ligament, left and right triangular ligaments, and coronary ligament to fully mobilize the liver. Then, under laparoscopy, the left hepatic duct, hepatic artery, and branches of the portal vein were separated, clipped, and divided with titanium clips.

Fig. 1. Locations of portals A, B, C, and D for laparoscopic liver resection. Portal A (laparoscope) was located in the left abdomen below the third nipple from the tail and 3-5 cm from the midline. A 10-mm trocar was placed, and a 30° laparoscope was inserted. Portal B was located approximately 5.00 cm lateral to the third nipple from the tail in the right abdomen, and a 10-mm trocar was placed for laparoscopic surgical instrument access. Portal C was located 3.00 - 5.00 cm below the right costal margin, and a 5.00-mm trocar was placed for laparoscopic surgical instrument access. Portal D was situated on the left side of the abdominal midline at the opposite side of portal C, and a 5.00-mm trocar was placed for laparoscopic surgical instrument access.

Fig. 2. A high-frequency electric scalpel was used to divide the liver parenchyma.
Fig. 3. Two needles threaded with one silk suture were used to penetrate the left hepatic lobe.

Fig. 4. Double-row transfixing ligation of the right lateral hepatic lobe.

Electrocoagulation and gauze compression was used for hemostasis. Then, the right hepatic parenchyma was divided along the straight double-row ligation line. During the liver parenchyma division, a titanium clip or transfixing suture was used to secure the divided end of the vessels when needed. Before the end of the procedure, medical bioprotein glue was applied to the incised liver section, and hemostatic gauze was used to cover the incised section. The omentum was also sutured to the incised area when it was necessary.

The incised liver section was examined to confirm that no bleeding was present (Fig. 5). A specimen bag was placed into the abdominal cavity through a trocar incision and the resected liver was placed in the bag. The right abdominal trocar incision was extended to remove the resected liver and abdominal drainage tube was placed through a trocar incision into the abdomen and secured. The abdominal wall was closed via a conventional suture.

The seven pigs in the OH group underwent open hepatectomy performed by the same group of surgeons; the double-row transfixing ligation of the hepatic lobe and electrocoagulation was also applied.

Postoperative care. After surgery, each miniature pig was individually placed in a warm and dry pig house to recover from anesthesia. The physiological parameters (e.g., body temperature, heart rate, respiratory rate, and blood pressure) were closely monitored until they returned to baseline levels. Intramuscular buprenorphine (0.01 mg kg$^{-1}$; Hansen Pharma Co. Ltd., Changsha, China) was administered after surgery for analgesia, and ampicillin (20.00 mg kg$^{-1}$; Lukang Pharma, Jining, China) was administered after surgery every 8 hr for three consecutive days. All animals were clinically examined daily, and white blood cell (WBC) counts were performed. The WBC count was determined using an automatic blood cell analyzer and its corresponding reagents (Mindray Biomedical Electronics Co. Ltd., Shenzhen, China). The drainage tube was cleaned every day and removed 3 – 5 days after surgery. Laparoscopic exploration was performed in both groups one month after surgery to determine whether abnormalities or adhesions were present throughout the abdominal cavity.

Measurements of CRP, IL-6, and COR concentrations. In the both groups, blood samples were collected from the anterior vena cava before surgery and at 1, 2, 3, 5, and 7 days after surgery, before morning feeding. Serum was separated, and CRP, IL-6, and COR concentrations were measured using enzyme-linked immunosorbent assay kits (Yapp Biological Technology Co. Ltd., Shanghai, China).

Statistical analyses. The operative time, estimated blood loss, incision length, the resected hepatic lobe's weight, and the number of intraoperative and postoperative complications were documented. The operative time was measured as the time from skin incision to skin closure. Blood loss was estimated from the total amount of liquid in the suction container minus the amount of washing liquid. SPSS (version 17.0; IBM Corp., Armonk, USA) was used for the statistical analyses. A one-way ANOVA was used to compare the differences at different time points between and within the groups. The data were expressed as mean ± SEM. The $p < 0.05$ was considered as a significance level.
Results

Surgical and clinical outcomes. In this study, a left hemihepatectomy combined with a right lateral hepatic lobectomy was completed in seven miniature pigs. The average operative time was 139.00 ± 9.07 min, which was longer than that of the OH group (121.67 ± 3.02 min; 0.01 < p < 0.05). The resected hepatic lobes' weights were similar in the two groups (343.86 ± 69.13 g versus 335.33 ± 23.98 g, LH group versus OH group, respectively). The incision length was significantly longer in the OH group than in the LH group (17.93 ± 1.09 versus 5.10 ± 0.17 cm; p < 0.01). The mean blood loss was estimated to be 136.43 ± 63.24 mL in the LH group and 208.67 ± 30.61 mL in the OH group (0.01 < p < 0.05). In the LH group, one case of subcutaneous emphysema was observed during surgery, and one pig in the OH group presented with slight oozing of the incised liver section. No serious complications (e.g., massive bleeding, bile leakage, or air embolism) were observed. All experimental pigs showed mild discomfort on the day of surgery, but no painful symptoms (e.g., bowing and trembling) were observed. On day one, after surgery, the pigs’ alertness and appetite were nearly restored, a small amount of fluid feeding was initiated, and their body temperatures increased slightly. After surgery, the drainage fluid gradually decreased and became clearer. The abdominal drainage tube was removed after 3 to 5 days. Sutures were removed 7 to 9 days after surgery. Except for a mild incision infection in one pig, the incisions were well healed. Laparoscopic exploration was performed one month after surgery, and adhesions were noted between the incised liver section and omentum or stomach wall. Otherwise, no abnormalities were found in the abdominal cavity.

White blood cell count. At 24 hr after surgery, the WBC count increased from 8.93 ± 0.27 to 15.33 ± 0.56 × 10^9 L^-1 (p < 0.01) and from 9.54 ± 2.12 to 22.14 ± 1.60 × 10^9 L^-1 (p < 0.01) in the LH and OH groups, respectively. The difference between these groups was significant (0.01 < p < 0.05). On the third day after surgery, the number of WBCs in the OH group was significantly higher than that in the LH group (p < 0.01). The WBC count in the LH group returned to the preoperative level three days after surgery, whereas that in the OH group returned to the preoperative level five days after surgery (i.e., WBC recovery occurred earlier in the LH group than OH group; Table 1).

Serum CRP, IL-6, and COR concentrations. Serum CRP increased initially and then decreased in the two groups. In the LH group, the serum CRP level peaked one day after surgery, and it was significantly higher than that before surgery (p < 0.01). The CRP level significantly differed from that before surgery two days after surgery (0.01 < p < 0.05), but it was not significantly different three days after surgery (p > 0.05). At two days after surgery, the serum CRP level was significantly different between the LH and OH groups (0.01 < p < 0.05), and this difference was significant three days after surgery (p < 0.01). At five and seven days after surgery, the serum CRP levels did not significantly differ between groups (p > 0.05).

The serum IL-6 level in the LH group was significantly higher 1 and 2 days after surgery than before surgery (p < 0.01), peaked one day after surgery, and returned to its preoperative level on the 3rd postoperative day. The changing trend of the serum IL-6 level in the OH group was similar to that in the LH group, which was significantly increased 1, 2, and 3 days after surgery compared to before surgery (p < 0.01) and returned to its preoperative level on the 5th postoperative day. The serum IL-6 concentration at 1, 2, and 3 days after surgery significantly differed between the LH and OH groups (p < 0.01). The differences in IL-6 at other time points were not significant (p > 0.05).

The COR concentrations in the LH group significantly differed from those before surgery 1 and 2 days afterward (p < 0.01) but returned to their preoperative level 3 days after surgery (p > 0.05). The COR level significantly differed between the LH and OH groups 1, 2, and 3 days after surgery (0.01 < p < 0.05). The differences in the COR level at other time points were not significant (p > 0.05).

Discussion

Successful partial hepatectomy procedures using porcine models have been previously reported. However, most of these procedures require expensive equipment such as LigaSure, an ultrasonic scalpel, and an Endo-GIA Stapler.\(^{24}\) In this study, liver parenchyma was laparoscopically

Table 1. White blood cell (WBC) count and serum levels of cortisol (COR), interleukin-6 (IL-6), and C-reactive protein (CRP) at different time points after surgery.

| Time points | WBC (× 10^9 L^-1) | CRP (mg L^-1) | IL-6 (pg mL^-1) | COR (ng mL^-1) |
|-------------|------------------|---------------|----------------|----------------|
|             | LH               | OH            | LH             | OH             | LH            | OH            | LH             | OH             |
| Pre-Op      | 8.93 ± 0.27      | 9.54 ± 2.12   | 1.19 ± 0.05    | 1.28 ± 0.19    | 32.39 ± 1.79  | 33.25 ± 2.30  | 21.03 ± 2.30   | 20.88 ± 1.07   |
| POD-1day    | 15.23 ± 0.56     | 22.14 ± 1.60  | 2.35 ± 0.03    | 2.74 ± 0.24    | 55.31 ± 1.57  | 69.23 ± 2.81  | 32.64 ± 1.30   | 39.03 ± 1.27   |
| POD-2day    | 12.14 ± 1.03     | 16.48 ± 2.14  | 1.46 ± 0.12    | 1.89 ± 0.08    | 46.69 ± 2.65  | 61.57 ± 1.44  | 30.53 ± 1.66   | 38.68 ± 2.31   |
| POD-3day    | 9.38 ± 1.57      | 12.56 ± 0.89  | 1.21 ± 0.10    | 1.48 ± 0.05    | 37.03 ± 2.30  | 51.80 ± 1.99  | 25.87 ± 2.48   | 34.30 ± 1.36   |
| POD-5day    | 8.62 ± 1.43      | 9.85 ± 0.66   | 1.10 ± 0.08    | 1.07 ± 0.11    | 33.88 ± 1.73  | 36.54 ± 2.57  | 23.77 ± 3.65   | 22.80 ± 2.15   |
| POD-7day    | 9.15 ± 0.63      | 10.05 ± 0.46  | 1.25 ± 0.07    | 1.40 ± 0.09    | 34.02 ± 1.87  | 34.56 ± 1.72  | 22.47 ± 2.58   | 19.86 ± 1.65   |

Pre-Op: Pre-operative; POD: Postoperative day; LH: Laparoscopic hepatectomy; OH: Open hepatectomy.

* 0.01 < p < 0.05, ** p < 0.01 compared with preoperative values and ▲ 0.01 < p < 0.05, ▲▲ p < 0.01 compared with the OH group.
ligated with double-row transfixing sutures. A left hemihepatectomy was successfully combined with a right lateral hepatic lobectomy using titanium clips and a high-frequency electrocautery scalpel. This simplified method for creating animal models of partial hepatectomy does not require additional specialized instruments or equipment, reduces the difficulty of model establishment, facilitates to replicate and apply the model, and facilitates the model's replication application.

During the operation, the ligaments around the liver should first be divided. Care should be taken during dividing of the coronary ligament, which should not be divided entirely to avoid injury to the posterior vena cava. Unlike the human hepatic anatomy, the hepatic vein of a pig near the diaphragm is buried in the liver parenchyma. Dissection of the hepatic vein here can cause massive bleeding, air embolism, and even death. Therefore, the hepatic vein was not dissected in this study; instead, the liver parenchyma was ligated at the base segment of the liver using transfixing ligation along the fissure between the liver lobes; then, the liver parenchyma was directly divided with a bipolar electrocoagulation hook. Based on our experience, after the full mobilization of the liver lobes, resection can be performed in the following order: First, the left hepatic lobe is ligated, but not removed; after the right lateral lobe is ligated, the right lateral hepatic lobe and left hepatic lobe can be removed together. This sequence improves the efficiency of surgery and facilitates the operation. During the liver parenchyma division, the liver lobe should be retracted as far as possible toward the posterior abdominal cavity to prevent the contraction and burning of the diaphragm muscles with the high-frequency electrosurgical current. Burning of the diaphragm muscles can cause pneumothorax. Using a high-frequency electric scalpel to divide the liver parenchyma, the resection line should be 1.00 - 2.00 cm away from the ligation line to avoid damaging the sutures and causing bleeding from the incised section. If bleeding occurs, then electrocautery, large titanium clips, and transfixing ligation technique can be used for hemostasis accordingly.

Compared to traditional open surgery, minimally invasive laparoscopic surgery has obvious advantages, such as a small incision in the abdominal cavity and laparoscopic visualization. However, the effect of an extensive hepatectomy on inflammatory response in miniature pigs and comparisons with traditional open surgery had not been fully evaluated or reported. The WBCs and CRP are sensitive indicators of various surgical complications (e.g., inflammation, tissue damage and sepsis). The IL-6 is also an indicator used to evaluate the severity of surgical trauma. Our study revealed that WBC, CRP and IL-6 concentrations were significantly higher and returned more slowly to preoperative levels after open hepatectomy compared to laparoscopic hepatectomy.

The effects of two surgical approaches on the metabolic response of the body were also significant. The serum COR concentration in two groups of animals increased significantly after surgery and gradually returned to the normal preoperative levels three days later. These findings are consistent with previously reported inflammatory responses between laparoscopic and open cholecystectomy. Therefore, our results showed a lower inflammatory response in the LH group than the OH group. Laparoscopic hepatectomy has clinical advantages over open hepatectomy because of its lower inflammatory response, fewer postoperative complications, and fewer intra-abdominal adhesions.

This study described a laparoscopic left hemihepatectomy combined with a right lateral hepatic lobectomy using a 4-trocar method. It demonstrated that the body's inflammatory response caused by LH is lower than that caused by OH. From technical and physiological perspectives, the LH approach seems feasible. Additional evaluation is needed to assess the LH approach's long-term effects in porcine models to improve biomedical research models in the future.

Acknowledgments

We are grateful to all of those who helped with this study. The National Natural Science Foundation of China (Grant No. 31702302, 31802091), the Da Bei Nong Foundation for Young Teachers (15ZK006), the Young Teacher Research Fund of BUA (SXQN2016105), and the Beijing Education Commission Science and Technology Project (SQKM201710020011) supported this study.

Conflict of interest

The authors have no conflict of interest to declare.

References

1. Kanazawa A, Tsukamoto T, Shimizu S, et al. Laparoscopic hepatectomy for liver cancer. Dig Dis 2015; 33(5):691-698.
2. Chen K, Pan Y, Maher H, et al. Laparoscopic hepatectomy for elderly patients: Major findings based on a systematic review and meta-analysis. Medicine (Baltimore) 2018; 97(30):e11703. doi: 10.1097/MD. 0000000000011703.
3. Cherqui D, Soubrane O, Hussine E, et al. Laparoscopic living donor hepatectomy for liver transplantation in children. Lancet 2002; 359(9304):392-396.
4. Hong SK, Suh KS, Kim HS, et al. Pure 3D laparoscopic living donor right hemihepatectomy in a donor with separate right posterior and right anterior hepatic ducts and portal veins. Surg Endosc 2017; 31(11):4834-4835.
5. Au KP, Chok KSH. Minimally invasive donor
hapatectomy, are we ready for prime time? World J Gastroenterol 2018; 24(25):2698-2709.

6. Eiriksson K, Fors D, Rubertsson S, et al. Laparoscopic left lobe liver resection in a porcine model: a study of the efficacy and safety of different surgical techniques. Surg Endosc 2009; 23:1038-1042.

7. Makabe K, Nitta H, Takahara T, et al. Efficacy of occlusion of hepatic artery and risk of carbon dioxide gas embolism during laparoscopic hepatectomy in a pig model. J Hepatobiliary Pancreat Sci 2014; 21(8):592-598.

8. Diana M, Usmaan H, Legnér A, et al. Novel laparoscopic narrow band imaging for real-time detection of bile leak during hepatectomy: proof of the concept in a porcine model. Surg Endosc 2016;30(7):3128-3132.

9. Budai A, Fulop A, Hahn O, et al. Animal models for associating liver partition and portal vein ligation for staged hepatectomy (ALPPS): Achievements and future perspectives. Eur Surg Res 2017, 50(3-4):140-157.

10. Sang JF, Shi XL, Han B, et al. Combined mesenchymal stem cell transplantation and interleukin-1 receptor antagonism after partial hepatectomy. World J Gastroenterol 2016;22(16):4120-4135.

11. Compagnon P, Levesque E, Rentati H, et al. An oxygenated and transportable machine perfusion system fully rescues liver grafts exposed to lethal ischemic damage in a pig model of DCD liver transplantation. Transplantation 2017; 101(7): e205-e213. doi: 10.1097/TP.0000000000001764.

12. Iguchi K, Hatano E, Nirasawa T, et al. Chronological profiling of plasma native peptides after hepatectomy in pigs: Toward the discovery of human biomarkers for liver regeneration. PLoS ONE 2017; 12: e0167647. doi:10.1371/journal.pone.0167647.

13. Bucur PO, Bekheit M, Audebert C, et al. Modulating portal hemodynamics with vascular ring allows efficient regeneration after partial hepatectomy in a porcine model. Ann Surg 2018; 268(1):134-142.

14. Glorioso JM, Mao SA, Rodysill B, et al. Pivotal preclinical trial of the spheroid reservoir bioartificial liver. J Hepatol 2015; 63(2):388-398.

15. Athanasiou A, Kontos M, Pikoulis E, et al. Extended hepatectomy using the bipolar tissue sealer: an experimental model of small-for-size syndrome in pigs. J BUON 2016; 21(6):1403-1409.

16. Fonouni H, Kashfi A, Stahlheber O, et al. Analysis of the biliostatic potential of two sealants in a standardized porcine model of liver resection. Am J Surg 2017; 214(5):945-955.

17. Gouda B, Massol J, Fuks D, et al. Minimally-invasive surgery for liver metastases. Minerva Chir 2015; 70:429-436.

18. May LR, Mehler SJ. Complications of hepatic surgery in companion animals. Vet Clin North Am Small Anim Pract 2011; 41(5):935-948.

19. Ruiz-Tovar J, Oller I, Galindo I, et al. Change in levels of C-reactive protein (CRP) and serum cortisol in morbidly obese patients after laparoscopic sleeve gastrectomy. Obes Surg 2013;23(6):764-769.

20. Okholm C, Goetze JP, Svensden LB, et al. Inflammatory response in laparoscopic vs. open surgery for gastric cancer. Scand J Gastroenterol 2014, 49(9):1027-1034.

21. Krog AH, Thorsby PM, Sahba M, et al. Perioperative humoral inflammatory response to laparoscopic versus open aortobifemoral bypass surgery. Scand J Clin Lab Invest 2017;77(2):83-92.

22. Mendoza-Sagaon M, Hanly Ej, Talaimini MA, et al. Comparison of the stress response after laparoscopic and open cholecystectomy. Surg Endosc 2000;14: 1136-1141.

23. Krikri A, Alexopoulos V, Zoumakis E, et al. Laparoscopic vs. open abdominal surgery in male pigs: marked differences in cortisol and catecholamine response depending on the size of surgical incision. Hormones (Athens) 2013;12(2):283-291.

24. Jerensius U, Fors D, Rubertsson S, et al. Laparoscopic parenchymal division of the liver in a porcine model: comparison of the efficacy and safety of three different techniques. Surg Endosc 2007; 21:315-320.

25. Alcaraz A, Musquera M, Peri L, et al. Feasibility of transvaginal natural orifice transluminal endoscopic surgery-assisted living donor nephrectomy: is kidney vaginal delivery the approach of the future? Eur Urol 2011;59(6):1019-1025.

26. Gehrig T, Manzini G, Fonouni H, et al. Comparison of two different transaction techniques in liver surgery—an experimental study in a porcine model. Langenbecks Arch Surg 2013; 398(6):909-915.

27. Court FG, Wemyss-Holden SA, Morrison CP, et al. Segmental nature of the porcine liver and its potential as a model for experimental partial hepatectomy. Br J Surg 2003; 90(4):440-444.

28. Beard RE, Tsung A. Minimally invasive approaches for surgical management of primary liver cancers. Cancer Control 2017;24(3):1073274817729234. doi: 10.1177/1073274817729234.

29. Liu CA, Huang KH, Chen MH, et al. Comparison of the surgical outcomes of minimally invasive and open surgery for octogenarian and older compared to younger gastric cancer patients: a retrospective cohort study. BMC Surg 2017;17:68. doi:10.1186/s12893-017-0265-3.

30. Shibata J, Ishihara S, Tada N, et al. Surgical stress response after colorectal resection: a comparison of robotic, laparoscopic, and open surgery. Tech Coloproctol 2015; 19(5):275-280.

31. Pohdnán R, Ryska M, Kalvach J, et al. Laparoscopic versus open left pancreatectomy: surgical stress response comparison in the porcine model [Czech]. Rozhl Chir 2018; 97(5):234-238.