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Optimum Hepatic Parenchymal Dissection to Prevent Bile Leak : A Comparative Study Using Electrosurgical and Stapling Devices in Swine

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Abstract

Background : Bile leakage is a serious complication of liver resection, and its treatment is very time-consuming. In open liver resection, Glisson's sheaths are usually disconnected by ligation to the extent possible during the parenchyma dissection. However, in laparoscopic surgery, the ligation, suture, and hemostasis are more difficult than in open surgery. For this reason, in laparoscopic liver resection, liver parenchyma dissection is generally accomplished using electrosurgical or stapling devices.

Purpose : The purpose of this study was to verify the authenticity of electrosurgical devices attached an automatic irrigation function (AI) and stapling devices for laparoscopic liver parenchymal dissection.

Methods : Four devices were used for liver parenchymal dissection in laparoscopic hepatic wedge resection, in pigs : monopolar high-frequency electric cautery attached AI (MCI) (n = 6), bipolar high-frequency electric cautery attached AI (BCI) (n = 6), bipolar tissue sealing system (LigaSure™) attached AI (BSI) and an endoscopic stapling device (ECHELON FLEX™ ENDOPATH®) (ES). In each group, burst pressures were tested using an electronic manometer, paying special attention to the location (s) of the first disruption (s). The dissected tissues were examined histologically.

Results : Pressures used in electrosurgical devices attach AI were significantly higher compared to pressures used in a ES ($P < 0.001$). While thermal denaturation of the liver parenchyma occurred at approximately 2-3 mm of depth when bipolar high-frequency electric cautery was used for dissection, it reached up to more than 10 mm with monopolar high-frequency electric cautery. All of the first disruption points of stapling were at stapling line.

Conclusions : Electrosurgical devices with an automatic irrigation function are useful devices to dissect the liver parenchyma.

Key words : Laparoscopic hepatectomy・Bile leak・Electrosurgical devices・Stapling devices・Burst pressure

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Introduction

The origin of laparoscopic surgery of the liver can be traced back to wedge liver biopsies performed as part of laparoscopic staging of lymphoma[1]. The first laparoscopic non-anatomic liver resection for focal nodular hyperplasia was reported by Gagner, et al[2] in 1992. This was followed by the first report of laparoscopic anatomical liver resection in 1996[3]. Since that time, improvements in laparoscopic devices have significantly improved the surgeon's ability to perform these procedures safely[4]. More advanced laparoscopic liver resections are now possible[4], including right hepatectomies[5)6)] and left hepatectomies.

The possibility of death during laparoscopic liver resection has been reported to be very low. Bleeding is an intraoperative complication that can necessitate conversion to open surgery. Postoperative bile leak is one of the most serious complication of laparoscopic liver resection. Various equipment and techniques have been developed for prevention of bleeding and hemostasis, during laparoscopic liver resection without ligation during parenchymal dissection. Currently, the cause of bile leakage after laparoscopic liver resection has not yet been clarified. The purpose of the present study is to determine if laparoscopic parenchymal dissection without ligation causes postoperative bile leak.

Methods

Animal care

Six healthy, female Japanese domestic pigs, 3 to 4 months of age and weighing 30 to 38 kg, were used in this study, which was conducted in full accordance with the principles outlined in the Declaration of Helsinki and an approval by the Institutional Review Board for animal studies. The animals were fasted the night prior to the experiment, but were allowed free access to water. Ketamine, 10 mg/kg was administered intramuscularly for initial sedation, and venous access was obtained by cannulation of the marginal ear vein using a large-gauge venous catheter. Atropine, 0.05 mg/kg IV, was given 5 min before intubation to help dry secretions ; and anesthesia was maintained with 1% napental, 0.5 mL/kg IV, as required. The pigs were intubated endotracheally and anesthesia was maintained with a mixture of nitrous oxide, oxygen, and isoflurane (Forane, Dainabot Ltd., Tokyo, Japan) administered via an endotracheal tube. Perioperative fluids consisted of Plasmalyte (balanced salt solution) at 20 mL/kg. Oxygen saturation and heart rate were monitored using pulse oximetry, placed on the ear.

Operative technique

After general anesthesia, the pig was placed in the supine position. The camera port was inserted via a small incision (1.5 cm) at a site left of midline and above the umbilicus. Additionally, 4 or 5 ports were placed under vision.

Segmental anatomy of pig liver

The pig liver can be divided into four lobes (left lateral lobe, left medial lobe, right medial lobe, and right lateral lobe). Each lobe has its own arterial and venous supplies, and biliary drainage.

Instruments used for hepatectomy

The monopolar high-frequency electric cautery attached an automatic irrigation function (AI) (MCI) (n = 6) (Fig 1), the bipolar high-frequency electric cautery attached AI (BCI) (n = 6), bipolar tissue sealing system (LigaSure™) (Covidien, New Haven, CT) attach AI (BSI) and an endoscopic stapling device (ECHELON FLEX™ ENDOPATH® (Ethicon Endo-surgery ; Johnson & Johnson, Cincinnati, OH, USA) (ES) was used as a stapling device. All monopolar and bipolar electrosurgical devices were used in the VIO (VIO 300D ; ERBE Elektromedizin, Tübingen, Germany) soft coagulation or VIO soft bipolar mode to keep the voltage below 200 V so that sparks did not occur. Similarly, the LigaSure™ was also used at a

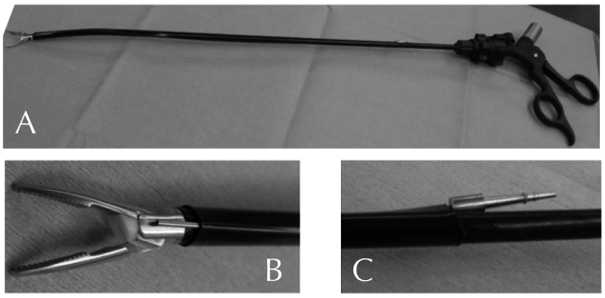

Fig. 1 The prototype forceps of monopolar high-frequency electric cautery attached an automatic irrigation function. The overall picture is shown A, the tip spout is shown B and the water supply inlet is shown C.

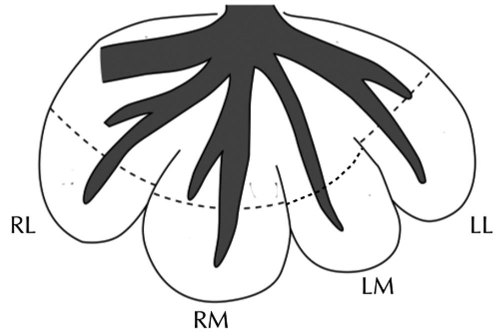

Fig. 2 Segmental anatomy of pig liver are shown, the pig liver can be divided into four lobes (left lateral lobe, left medial lobe, right medial lobe, and right lateral lobe). The wedge resection of each lobe were performed along the dotted line.

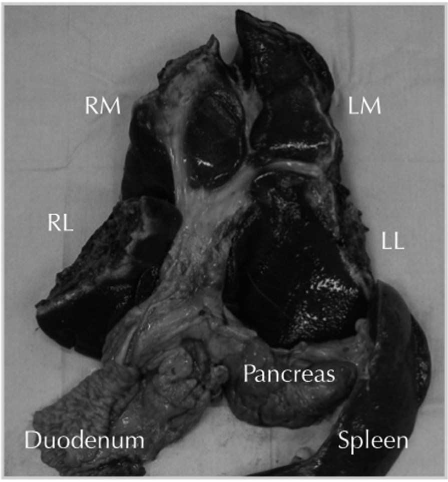

Fig. 3 Removed liver, pancreas, spleen and duodenum after wedge liver resections.

Fig. 4 A 4 Fr vinyl chloride tube was inserted through the papilla of Vater, (arrow).

setting of less than 200 V to avoid sparks. Resection with stapling was performed without coagulation. Two 60 mm green cartridges were used for each lobe resection. The once stapling was performed slowly over 5 minutes to once stapling.

Liver resection

A wedge resection in the portion of the liver, approximately 8 cm from the lateral edge of the left lateral lobe, right lateral lobe, left medial lobe and right medial lobe were performed using one instrument randomly selected for each lobe (Fig. 2). Following each wedge resection, the amount of blood lost was calculated by subtracting the amount of blood irrigated from the amount of blood suctioned each wedge resection.

Pressure test of the anastomosis

After laparoscopic resection complete hemostasis was confirmed (Fig. 3), and the liver, pancreas, and duodenum were excised en bloc. A 4 Fr vinyl chloride tube was inserted through the papilla of Vater (Fig. 4), and the pressure resistance of each resected surface was tested. Air leakage was monitored by placing the specimens in a water-filled basin and observing for escape of air bubbles. Burst pressure was measured, using an electronic manometer (PG-100N, Copal electronics, Tokyo, Japan) and was defined as pressure recorded the moment air leak began. Special attention was paid to the location (s) of the disruption(s). Statistical differences between groups were analyzed using JMP 9.0 software with the student's t test.

Histological examination of the regions of anastomosis

To evaluate thermal damage, the transected liver surface was dissected. The tissue was fixed ; embedded in paraffin ; sections were serially cut ; and stained with hematoxylin and eosin. Histological analysis was done to determine the presence and extent of thermal damage.

Results

All resections were performed as planned. Resection with stapling devices was completed in less than 15 minutes, whereas resection with electrosurgical device took approximately 30 minutes. However, after resection with stapling devices, an additional procedure, compression hemostasis was usually needed for complete control of the bleeding.

The resection times were as follows : MCI (n = 6), 26.83 ± 8.13 min ; BCI (n = 6), 32.67 ± 6.8 ; BSI, 28.67 ± 8.31 ; and ES, 12.67 ± 1.63 min. Resection times were significantly shorter using a ES compared with an electrosurgical device (MCI, BCI, and BSI) ($P < 0.001$).

Blood loss during resection was as follows : MCI (n = 6), 50.5 ± 35.63 ml ; BCI (n = 6), 45.33 ± 30.01 ; BSI, 86 ± 13.52 ; and ES, 126 ± 42.03 ml. Blood loss was significantly higher with the stapling device compared with electrosurgical devices device ($P < 0.001$) (Table 1).

The pressure resistances were as follows : MC (n = 6), 159.33 ± 42.03 mmHg ; BC (n = 6), 181.5 ± 46.93 ; LigaSure™, 188.17 ± 60.2 ; and ENDOPATH™, 73.33 ± 16.23 mmHg. Pressure resistance was significantly lower using a stapling device compared to an electrosurgical device ($P < 0.001$) (Table 1).

The first bursts occurred on the staple lines when using a ES. However, when using an electrosurgical device (MC, BC and BSI), the first bursts occurred at sites other than the resected surface in most cases.

Table 1. Results of wedge liver resection.

Devices		Number	Resection time (min)	P	Blood loss (ml)	P	Pressure resistance (mmHg)	P
Electrosurgery	MCI	6	26.83 ± 8.13		19.83 ± 11.43		159.33 ± 42.03	
	BCI	6	32.67 ± 6.8		16.50 ± 10.1		181.5 ± 46.93	
	BSI	6	28.67 ± 8.31	<0.01	24.5 ± 11.46	<0.01	188.17 ± 60.2	<0.01
Staple	ES	6	12.67 ± 1.63		75.33 ± 20.26		73.33 ± 16.23	

MCI: monopolar high-frequency electric cautery attached an automatic irrigation function.

BCI: bipolar high-frequency electric cautery attached an automatic irrigation function.

BSI: bipolar tissue sealing system (LigaSure™) attached an automatic irrigation function.

ES: endoscopic stapling device (ECHELON FLEX™ ENDOPATH®).

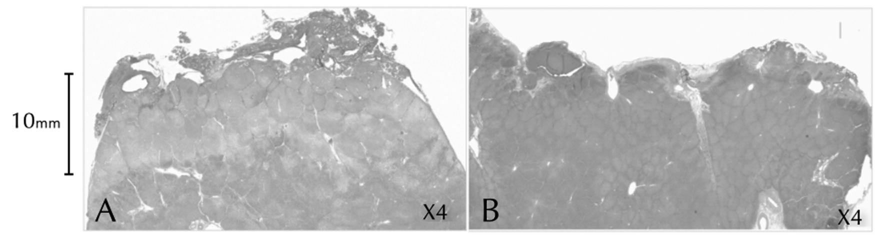

Fig. 5 A : Histological examination revealed the thermal damage with monopolar (MCI) was deeper than 10 mm.
B : The thermal damage with bipolar (BCI and BSI). The thermal damage was usually 2 to 3 mm deep with bipolar sealants, including LigaSure®.

Histological examination of resected areas

Histological examination revealed the thermal damage was deeper with monopolar (MCI) compared to bipolar (BCI and BSI). The thermal damage was usually 2 to 3 mm deep with bipolar sealants, including LigaSure™ whereas it was ≥ 10 mm deep with monopolar devices (Fig. 5).

Discussion

When dissecting liver parenchyma, it is important to control bleeding in order to ensure dissection of the exact site of interest. Major bleeding causes severe complications in laparoscopic liver surgery because immediate compression cannot be achieved with a laparoscopic instrument, and manual control by the surgeon is not feasible. Therefore special equipment to control bleeding during parenchymal transection is required during laparoscopic liver resection. Saline-enhanced high-frequency electrosurgical monopolar or bipolar devices have been developed for this purpose. These devices have a spherical or acicular tip to coagulate blood along the transection line. When these electrosurgical devices were used, very little intraoperative bleeding was encountered during the transection of the liver parenchyma, making laparoscopic liver resection easier. However, the internal structures and vessels of the liver cannot be visualized during laparoscopic resection, which can lead to heat damage to deeply seated vessels, such as bile duct, which could result in bile leakage after surgery[8)~12)].

Although there are reports of the use of laparoscopy for major liver resection[5)6)], laparoscopic technique should ideally be reserved for resection of small, peripherally located tumors in the lower or lateral segments of liver. The benefits of the laparoscopic approach over open surgery include a more rapid improvement in serum transaminase levels, a reduced need for postoperative analgesia, a shorter delay for oral intake, and a shorter hospital stay[10)]. Disadvantages of laparoscopic liver resection include difficulty in retracting and mobilizing the liver and identifying tumor margins[12)]. When performing right or left hemihepatectomy, some surgeons have used a stapling device to divide not only the Glissonian sheath but also the liver parenchyma and the hepatic veins, including thin veins such as the short hepatic vein. This stapling method makes laparoscopic liver resection easier and quicker ; however, if the transection occurs on the wrong separating line, serious complications, such as major bleeding from the hepatic vein or inappropriate division of the Glissonian sheaths can occur.

In this study, prototype monopolar and bipolar electrosurgical forceps, and scissors attached an automatic irrigation system were used for liver resection. These devices have been developed to take advantage of the saline irrigating effect of the high-frequency monopolar and bipolar electrosurgical devices, while preventing the carbonization of tissues. They also prevent the adherence of electrode tips to tissues during coagulation, which can cause bleeding when the tip and tissue are separated.

Porcine liver resection could not be performed with older electrosurgical devices that do not have the capability of automatic irrigation because of uncontrollable bleeding from the hepatic vein. However, when an electrosurgical device with an attached automatic irrigation function was used, very little intraoperative bleeding occurred during transection of the liver parenchyma, resulting in easier, more rapid laparoscopic liver resection with a lower postoperative complication rate.

In this study, the thickness of the porcine liver parenchyma was approximately 25 mm. When a stapling device was used for transection, the maximum thickness of crush injury to the parenchymal tissue, including the hepatic vein and Glissonian sheaths, was 2.8 mm. A substantial amount of bleeding was usually observed immediately after transection with the stapling devices ; however, the bleeding was controllable only by compression.

Therefore, the time required for resection using stapling devices was shorter than with electrosurgical devices. However, the average blood loss during resection was significantly greater with the stapling device than with the electrosurgical devices. In addition, the pressure resistance of the bile ductswas significantly lower with a stapling device than with electrosurgical devices. In all of the stapling resection cases, the bursting points were observed on the staple line, which means that Glissonian sheaths were included in the staple line. The pressure resistance of the stapling devices was above the upper limit of the physiological value of the internal pressure of the bile duct. There was no significant difference in amount of bleeding or bile duct pressure resistance performance between the 3 types of electrosurgical devices. However, histological evaluation revealed that the thermal damage by monopolar electrosurgical devices extended deeper into the tissue than that caused by bipolar devices. The pressure resistance of the bile duct was very high when either the monopolar or bipolar electrosurgical devices were used. Division of the Glissonian sheaths to less than 5 mm, which is usually required after ligation or clipping in open hepatectomy, might be unnecessary . Bile leakage after surgery is more likely to be caused by the heat damage to a deeply seated bile duct than by insufficient closure of the bile duct on the dissection surface.

Electrosurgical devices with an automatic irrigation function are useful devices to dissect the liver parenchyma. They allow laparoscopic liver resection to be performed more easily and quickly with fewer postoperative complications. Protein coagulation effect caused by the heat of monopolar electrocautery devices reached deeper into the liver parenchyma than that caused by bipolar electrocautery devices. The saline-enhanced monopolar electrocautery devices are useful to control bleeding from a relatively large, deep vein ; however, because of its deep penetration, it has the potential to damage the bile duct causing bile leakage.

Conclusions

Electrosurgical devices with an automatic irrigation function are useful devices to dissect the liver parenchyma.

Disclosures

Drs. Tetsuo Ikeda, MD, PhD[1], Tomohiko Akahoshi[1], Hirofumi Kawanaka, MD, PhD[2], Hideaki Uchiyama, MD, PhD[2], Yoichi Yamashita, MD, PhD[2], Masaru Morita, MD, PhD[2], Eiji Oki, MD, PhD[2], Hiroshi Saeki, MD, PhD[2], Keishi Sugimachi, MD, PhD[3], Toru Ikegami, MD, PhD[2], Tomoharu Yoshizumi, MD, PhD[2], Yuji Soejima, MD, PhD[2], Ken Shirabe, MD, PhD[2], Koshi Mimori, MD, PhD[3], Masayuki Watanabe, MD, PhD[4] makoto Hashizume[1] and Yoshihiko Maehara, MD, PhD[2] have no conflicts of interest or financial ties to disclose.

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（和文抄録）

腹腔鏡下肝切除における適切な肝実質切離方法の検討：電気手術器具と吻合器の比較検討

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【背景】術後胆汁漏は肝切除術の重大な合併症の一つであり，一旦発生すると治療に難渋する事も稀ではない．このため開腹下での肝切除においては，Glisson 鞘は可能な限り結紮して閉鎖されている．しかし，腹腔鏡下では結紮，縫合の操作は開腹手術に比べ極めて時間を要する．このため腹腔鏡下では肝実質切離も電気手術器機による凝固あるいは吻合器によって行われているのが現状である．
【目的】大動物（ブタ）を用いた肝切離において，電気手術器具あるいは吻合器での肝実質切離の安全性と胆汁漏の原因を検討する．
【方法】4 種類の器具①モノポラー高周波凝固器具に自動生理食塩水滴下装置を装着した器具（MCI），②バイポーラ高周波凝固器具に自動生理食塩水滴下装置を装着した器具（BCI），③バイポーラ血管シーリング装置（LigaSure™）に自動生理食塩水滴下装置を装着した器具（BSI），④腹腔鏡下自動吻合器（ECHELON FLEX™ ENDOPATH®）（ES）をを用いて腹腔鏡下に楔状肝切除を行った．切離時間，術中出血量，胆管の耐圧力測定および組織学的に比較検討した．
【結果】電気手術器機に比べ吻合器は切離時間は短く，出血量は多く，胆管耐圧力は低い結果であった．上記に関しては 3 種の電気手術器機間での違いは認められなかったが，組織学的にはモノポーラがボイポーラ電気手術器機に比べ，熱による肝実質障害が深い部分にまで及んでいた．
【結語】電気手術器具に自動生理食塩水滴下装置を装着した器具での肝実質切離では高い胆管耐圧力が得られ結紮の必要はないと考えられる．