

Application of stapling devices in liver surgery: Current status and future prospects

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Abstract

The liver is a vascular-rich solid organ. Safe and effective dissection of the vessels and liver parenchyma, and control of intraoperative bleeding are the main

concerns when performing liver resection. Several studies have confirmed that intraoperative blood loss and postoperative transfusion are predictors of postoperative morbidity and mortality in liver surgery. Various methods and instruments have been developed during hepatectomy. Stapling devices are crucial for safe and rapid anastomosis. They are used to divide hepatic veins and portal branches, and to transect liver parenchyma in open liver resection. In recent years, laparoscopic liver surgery has developed rapidly, and is now preferred by many surgeons. Stapling devices have also been gradually introduced in laparoscopic liver surgery, from dividing vascular and biliary structures to parenchymal transection. This may be because staplers make manipulation more simple, rapid and safe. Even in single incision laparoscopic surgery, which is recognized as a new minimally invasive technique, staplers are also utilized, especially in left lateral hepatectomy. For safe application of stapling devices in liver surgery, more related designs and modifications, such as application of a suitable laparoscopic articulating liver tissue crushing device, a staple line reinforcement technique with the absorbable polymer membrane or radiofrequency ablation assistance, are still needed. More randomized studies are needed to demonstrate the benefits and find broader indications for the use of stapling devices, to help expand their application in liver surgery.

Key words: Staplers; Liver resection; Laparoscopy

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Core tip: Stapling devices are crucial for safe and rapid anastomosis in gastrointestinal surgery. They have been gradually introduced in open hepatectomy and laparoscopic liver surgery for dividing vascular and biliary structures and parenchymal transection. Staplers make manipulation more simple, rapid and safe. Even in single incision laparoscopic surgery, staplers are

also utilized, especially in single incision laparoscopic left lateral hepatectomy. More related designs and modifications are still needed for safe application of stapling devices in liver surgery, and more randomized studies are needed to demonstrate the benefits and find broader indications for the use of stapling devices.

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INTRODUCTION

The liver is a vascular-rich organ, with the need to seal and divide multiple vascular and biliary structures during resection. Over the past 30 years our understanding of hepatic anatomy and improvement in technical skills to control major vascular and biliary structures has advanced; as a result, liver resection, including wedge resection, segmental resection, left lateral sectionectomy and hemihepatectomy, has gradually developed as the main effective treatment for primary and secondary malignancies, as well as for benign diseases of the liver.

During liver resection, safe and effective dissection of liver parenchyma, and control of intraoperative bleeding are the major concerns. Several studies have confirmed that intraoperative blood loss and postoperative transfusion are predictors of postoperative morbidity and mortality in liver surgery^[1,2]. Surgical technique is a major factor in prevention of complications, and various methods and instruments have been developed for safe dissection of the vessels and liver parenchyma. During liver surgery, suture and ligation of vascular and biliary structures are difficult and may be hazardous. Recently, several methods for parenchymal transection have emerged, including some selective and non-selective dissection methods. The former include the Cavitron Ultrasonic Surgical Aspirator technique and the jet cutter, whereas non-selective dissection methods include ultrasonic scalpel, scissors, high-frequency coagulation, laser technique and staplers^[3]. In this review, we outline the current status of application of stapling devices in open liver surgery, laparoscopic liver surgery, and single incision laparoscopic liver surgery (SILS), and look forward to their development and future application.

TENTATIVE APPLICATION OF STAPLING DEVICES IN OPEN LIVER SURGERY

Staplers are vital instruments in rectal, colonic and esophageal surgery, allowing safe and rapid anastomosis of the gastrointestinal tract even when

surgical exposure is compromised^[4]. Their application has expanded in many surgical procedures, and as early as 1989 they were already being used in open liver surgery to control the hepatic veins within the hepatic parenchyma^[5]. When precise isolation of the veins is difficult to achieve because they are located at the very bottom of the major scissura along the line of resection with oozing sidewalls, stapling devices can be placed over the tissue, compressed and fired to transect the hepatic vein^[5]. This stapled control of the hepatic veins can be used repeatedly with uniform success, and it is recommended as a quick and efficient technique for completing hepatic resection^[5]. Staplers have also been used to divide hepatic veins and portal branches. They can control both of the veins before parenchymal transection, reduce hemorrhage associated with major hepatic resection and efficiently assist in averting blood loss, thereby reducing the requirement for inflow occlusion^[3,5-8]. The use of staplers can also improve the speed and safety of ligation of both inflow and outflow vessels, and facilitate liver resection^[7-9].

Staplers have also been used for the transection of liver parenchyma, because they can seal any unexpectedly injured bile ducts or blood vessels^[7,9]. Transection of hepatic parenchyma with vascular staplers has been assessed, and its advantages include a low rate of biliary complications (*i.e.* bile fistulas and bilioma) and reduced bleeding^[10]. Stapled wedge resection of the liver and left lateral segmentectomy have been conducted, with favorable results^[8,11]. In performing hemihepatectomy or extended hemihepatectomy, adequate hepatic arterial, portal venous branch and appropriate hepatic veins can be divided with the endo-GIA vascular stapler or *via* suturing. To allow for subsequent dissection of the thicker hepatic parenchyma, the liver tissue can be fractured stepwise with a clamp and subsequently divided with endo-GIA vascular staplers^[10]. When necessary, intraoperative ultrasound can also be used to guide the dissection. Using this technique of liver resection, there is no need to perform Pringle's maneuver or other vascular control methods in most patients^[10,12]. It has been demonstrated that parenchymal transection with endo-GIA vascular staplers is a feasible and safe technique for liver resection with low mortality (4%) and morbidity (33%) in open liver surgery^[12].

APPLICATION OF STAPLING DEVICES IN LAPAROSCOPIC LIVER SURGERY

Laparoscopy has gradually become a widely accepted technical platform in nearly all areas of surgery, since its introduction with laparoscopic cholecystectomy in the late 1980s^[13]. Acting as a less-invasive alternative to open hepatectomy, laparoscopic liver resection has shown its superiority with regard to blood loss, postoperative recovery and hospital stay in selected

patients^[14,15]. The application of surgical staplers has also been attempted and extended to laparoscopic liver resection, and staplers have also been proven as a convenient and effective method^[16]. Staplers are being more frequently utilized in laparoscopic surgery, possibly because they make manipulation simpler and perhaps safer.

Similar to open liver surgery, application of staplers in laparoscopic liver surgery also began with ligation and dissection of inflow and outflow vessels of the liver. After complete or incomplete mobilization, total laparoscopic resection was performed with two or more endoscopic staples, applied sequentially, when necessary, across the portal pedicle and hepatic vein. Scuderi *et al.*^[16] retrospectively compared 35 laparoscopic liver resections with the Tri-Staple technology vs 57 laparoscopic liver resections without stapling. They found that, although the tumor size and number in the stapled group were larger than in the non-stapled group, the mean surgical time and blood loss of the two groups were similar. Furthermore, in the stapled group, the Pringle maneuver was also used less frequently, and the conversion and morbidity rates were lower, proving that the use of staplers is one of the most relevant technological advancements in laparoscopic liver resection, for safely dividing vascular and biliary structures.

Among laparoscopic liver resections, increasingly complex operations, such as extended right hepatectomy, mesohepatectomy and two-stage liver resection, have gradually been performed by experienced surgical groups or centers^[16-18]. In some of the reported cases, staples have also been used in parenchymal transection, and are thought to be a safer alternative for parenchymal dissection in laparoscopic liver surgery^[16,17]. Unlike open liver surgery, where the thicker hepatic parenchyma is fractured stepwise with a clamp, O'Rourke *et al.*^[17] have reported stratified dissection of the liver parenchyma, with the thin arm of the stapler insinuated through the liver, and the stapler fired after resistance is achieved. A repeat firing of the stapler, or suture ligation, is used to control the bleeding that most commonly occurs from branches of the middle vein. Buell *et al.*^[19] analyzed an international database of 1499 laparoscopic liver resections and compared 764 stapler hepatectomies with 735 electrosurgical resections. They found that, although used in larger tumors, stapler hepatectomy was completed within a shorter time, with less blood loss and shorter length of stay. This suggests that stapler hepatectomy is a safe and efficacious technique, especially for major hepatectomy, during laparoscopic liver resection. Buell *et al.*^[19] also found that, although having a smaller pathological margin, stapler hepatectomy still led to a similar incidence of recurrence as with electrosurgical dissection. One disadvantage of staplers in laparoscopic liver surgery, for ligation and dissection of inflow and outflow vessels, and even parenchymal transection,

is the increased cost of the disposable devices. It is reported that up to nine vascular staplers are used for parenchymal transection^[17]. However, the added costs of the staplers may be offset by shorter operating time and length of stay^[19].

APPLICATION OF STAPLING DEVICES IN SILS

Recently, SILS has emerged as a minimally invasive technique for further minimizing surgical trauma by reducing the number of access ports. SILS has shown a remarkable increase in use, as a result of the desire of surgeons for less-invasive procedures and the request of patients for techniques with better cosmetic outcome. SILS has now been applied in many fields of abdominal surgery, including liver surgery^[20-22]. However, during SILS, several laparoscopic instruments are introduced together with the endoscope through one single port. This can result in crossed instruments, and the proximity of the endoscope to the operating instruments can lead to instrument or trocar collision, making the operation more difficult to learn and perform than traditional laparoscopic surgery. The complex procedures of liver surgery make the application of single incision laparoscopic liver surgery (SIL-LS) more difficult and slow down its progress. To date, 200 cases have been reported^[23-62] (Table 1), and non-anatomical resection, segmentectomy and left lateral sectionectomy are still mainly performed for localized lesions and solitary tumors in the anterolateral segments of the liver, or left liver lobe^[26,29,37] (Table 1). Left hepatic resection has been reported in only two cases, and right hepatic resection in only one^[33,36].

For tumor enucleation, wedge resection or segmentectomy of the liver in SILS, the surrounding liver parenchyma is frequently transected through the proposed division line using an ultrasonic scalpel, LigaSure and endoclips. When approaching larger structures, such as branches of the hepatic veins and Glisson bundles, an endoscopic linear stapler is sometimes utilized. For some suitable cases, linear staplers were also selected for local tumor resection^[37], as in traditional laparoscopic wedge resection^[11]. Single-incision laparoscopic left lateral liver sectionectomy (SIL-LLS) has been reported in 83 cases. A stapler was not used in 10 cases^[23,46]. In the remaining 73 cases, a stapler was applied, most frequently for dividing the hepatic vein (70 cases) and the hepatic pedicle (hepatic artery, portal vein or bile duct) (64 cases) (Table 2). In addition, in single incision laparoscopic left (2 cases) and right (1 case) hepatectomy, a stapler was used for dissection of the hepatic vein. The hepatic duct was sectioned and clamped with a vascular stapler in 2 cases, and the portal vein was stapled and divided in 1^[33,36].

Stapling devices are helpful for vascular control and

Table 1 Demographics and interventions of 218 reported cases with single incision laparoscopic liver resection

| Ref. | No. of cases | Lesion type | | | | | | Intervention ¹ | | | | | | |
|---|-----------------|---------------|--------------------------|-----|----------------|-----|-----------------|---------------------------|---|--------------|-----------------|---------------|----------------------------|---------------------------------|
| | | Hepatic cysts | Hydatid disease of liver | FNH | CRC | HCC | Hepatic adenoma | Liver hemangioma | Others | Fenestration | Wedge resection | Segmentectomy | Left lateral sectionectomy | Others |
| Weiss <i>et al</i> ^[23] , (2015) | 21 | | | 4 | 6 | 1 | | 2 | 8 (1 abscess, 1 Caroli syndrome, 2 cholangiocellular cancer, 4 malignant metastasis from neuroendocrine tumor, gastric cancer, prostatic cancer or esophageal cancer) | | 11 ¹ | 2 | 9 | |
| Igami <i>et al</i> ^[24] , (2015) | 1 | 1 | | | | | | | | 1 | | | | |
| Willems <i>et al</i> ^[25] , (2015) | 1 | 1 | | | | | | | | 1 | | | | |
| Hu <i>et al</i> ^[26] , (2014) ¹ | 18 | | | 2 | | | 3 | 7 | 6 (Hepatolithiasis) | | | | 18 | |
| Machado <i>et al</i> ^[27] , (2014) | 8 | | | 1 | | | 6 | | 1 (cholangiocarcinoma) | | | | 8 | |
| Mantke <i>et al</i> ^[28] , (2010) | 1 | 1 | | | | | | | | 1 | | | | |
| Tan <i>et al</i> ^[29] , (2012) | 7 | | | | 2 ² | 4 | 2 | | 1 (Ovarian serous carcinoma liver metastasis) | 1 | 2 | | 5 | |
| Gaujoux <i>et al</i> ^[30] , (2011) | 5 | 1 | | | 2 | 1 | | | | | 4 | | | |
| Sasaki <i>et al</i> ^[31] , (2010) | 1 | 1 | | | | | | | | 1 | | | | |
| Toyama <i>et al</i> ^[32] , (2013) | 1 | | | | | | | | 1 (Hepatocellular-cholangiocarcinoma) | | 1 | | | |
| Shetty <i>et al</i> ^[33] , (2012) | 24 ³ | | | | | 24 | | | | | 4 | 13 | 4 | 1 LH, 1 RH |
| Soni <i>et al</i> ^[34] , (2011) | 1 | | 1 | | | | | | | | | | | Percutaneous hydatid cystectomy |
| Wu <i>et al</i> ^[35] , (2014) | 17 | | | 1 | 2 | 4 | 2 | 6 | 2 (Hepatolithiasis) | | 8 | | 9 | |
| Camps Lasa <i>et al</i> ^[36] , (2014) | 5 | | 1 | | 4 | | | | | | | | 4 | 1 LH |
| Zhao <i>et al</i> ^[37] , (2011) | 12 | | | 3 | | 2 | 1 | 6 | | | 8 | | 4 | |
| Pan <i>et al</i> ^[38] , (2012) | 8 | 2 | | | 1 | 4 | | 1 | | | 2 | 3 | 3 | |
| Chen <i>et al</i> ^[39] , (2013) | 1 | | | | | | | 1 | | | 1 | | | |
| Tayar <i>et al</i> ^[40] , (2014) | 7 | | | | 2 | 2 | 3 | | | | 7 | | 2 | |
| Kandil <i>et al</i> ^[41] , (2013) | 2 | | | | 1 | | 1 | | | | | 2 | 1 | |
| Kim <i>et al</i> ^[42] , (2014) | 3 | | | 3 | 3 | 5 | | 2 | 1 (Peripheric cholangiocarcinoma) | | 1 | | 13 | |
| Cipriani <i>et al</i> ^[43] , (2012) | 14 | | | | | | | | | | | | | |
| Tzanis <i>et al</i> ^[44] , (2014) | 3 | | | 1 | | 1 | 1 | | | | 2 | | 1 | |
| Patel <i>et al</i> ^[45] , (2011) | 1 | | | | 1 | | | | | | | | 1 | |
| Dapri <i>et al</i> ^[46] , (2012) | 6 | 3 | 2 | | 1 | | | | | 3 | 1 | 1 | 1 | |
| Wu <i>et al</i> ^[47] , (2014) | 15 | 15 | | | | | | | | 15 | | | | |
| Zhang <i>et al</i> ^[48] , (2011) | 4 | 4 | | | | | | | | 4 | | | | |
| Barbaros <i>et al</i> ^[49] , (2010) | 1 | | | | | | 1 | | | | 1 | | | |
| Kashiwagi <i>et al</i> ^[50] , (2011) | 1 | 1 | | | | | | | | 1 | | | | |

| | | | | | | |
|--|---|---|---|---|--------------------------|---|
| Rosok <i>et al</i> ^[51] , (2011) | 1 | 1 | 1 | 1 | 1 | 8 |
| Aikawa <i>et al</i> ^[52] , (2012) | 8 | 1 | 5 | 1 | 1 (Neuroendocrine tumor) | 1 |
| Chinnusamy <i>et al</i> ^[53] , (2013) | 1 | 1 | | | | 1 |
| Choi <i>et al</i> ^[54] , (2013) | 2 | 2 | | | | 2 |
| Imamura <i>et al</i> ^[55] , (2013) | 1 | 1 | | | | 1 |
| Eryilmaz <i>et al</i> ^[56] , (2014) | 1 | 1 | | | | 1 |
| Belli <i>et al</i> ^[57] , (2011) | 1 | | 1 | | | |
| Gocho <i>et al</i> ^[58] , (2013) | 6 | 6 | | | | 6 |
| Cai <i>et al</i> ^[59] , (2012) | 5 | 5 | | | | 5 |
| Kobayashi <i>et al</i> ^[60] , (2010) | 1 | | 1 | | | 1 |
| Karabacak <i>et al</i> ^[61] , (2013) | 1 | 1 | | | | 1 |
| Cai <i>et al</i> ^[62] , (2010) | 1 | | | 1 | | 1 |

¹One patient was converted to multiport laparoscopy, and the related data was not included in the article; ²One case with a 3-mm metastatic adenocarcinoma of colorectal origin found in postoperative diagnosis after HCC resection including a double-segment wedge resection; ³The detailed medical record of one patient was not available. CRC: Colorectal liver metastases; FNH: Focal nodular hyperplasia; HCC: Hepatocellular carcinoma; LH: Left hemihepatectomy; RH: Right hemihepatectomy.

routinely used in traditional laparoscopic hepatectomy^[63]. Stapling devices are also beneficial in SIL-LS. With the help of staplers, SIL-LLS can be finished smoothly. Hu *et al*^[26] compared single-port and multi-port laparoscopic left lateral liver sectionectomy for surgical treatment of benign liver disease. They found that the two groups had similar mean operating times and volumes of intraoperative blood loss, which was similar to the results reported by Aldrighetti *et al*^[64]. In addition, the average operating time and intraoperative blood loss for single-port laparoscopic left lateral hepatectomy (Table 2) were comparable with those for traditional laparoscopic hepatectomy^[65,66]. Unlike open surgery or traditional laparoscopic hepatectomy, in SIL-LS, staplers have not been reported for parenchymal transection in left lateral, left or right hepatectomy. As more SIL-LS procedures are performed, staplers may be attempted for parenchymal transection in left lateral, left or right hepatectomy, and more major hepatic resections may be attempted in SILS.

FUTURE PROSPECTS FOR APPLICATION OF STAPLING DEVICES IN LAPAROSCOPIC LIVER SURGERY

Staplers have been used successfully in multi-port laparoscopic hepatectomy for parenchymal transection, especially for larger tumors^[19]. However, in traditional laparoscopic hepatectomy and SIL-LS, staplers have been mostly limited to the division of major vascular and biliary structures. However, as more major hepatectomies are performed, staplers might gradually become effective and important devices in the near future, even in SIL-LS.

In hepatectomy, it is reported that, if liver tissues are thick and brittle, stapling is more likely to fail during the operation^[67]. Therefore, some suitable modifications of operating methods and skills might be needed, to improve the application of staplers for parenchymal transection in laparoscopic hepatectomy. When investigating the success rate of surgical stapling in *ex vivo* pig livers, tissue thickness had a greater effect on the success rate of surgical stapling than did tissue stiffness^[67]. If tissue thickness was 5–10 mm, the success rate of surgical stapling was high, and if tissue thickness was > 10 mm, the success rate was affected by nonlinear viscoelastic parameters^[67]. O'Rourke *et al*^[17] showed that, when the thickness of liver tissue was high, liver parenchyma was dissected in a stratified fashion, with the thin arm of the stapler insinuated through the liver parenchyma, and the stapler fired after resistance was achieved. It could be that, as with the procedure in open liver surgery, stepwise fracture of the liver tissue with a suitable clamp and subsequent dissection of the thick hepatic parenchyma is a more appropriate method^[10]. Although Otsuka *et al*^[68] proposed that a stapler could also be used as a crush-clamp device, a more suitable laparoscopic articulating liver tissue crushing device would be more helpful for using a stapler in parenchymal transection in laparoscopic hepatectomy, including SIL-LS. Buell *et al*^[19] also reported that stapler hepatectomy could result in a trend towards more complications, including bile leaks, but a new staple line reinforcement technique might resolve the problem^[69]. An absorbable polymer membrane was incorporated into the stapler system, to buttress the transected solid organ, decrease hemorrhage and prevent bile duct leakage at the staple line after liver

Table 2 Application of stapling devices in single incision laparoscopic left lateral liver sectionectomy

| Ref. | No. of cases with left lateral liver sectionectomy | Application of stapling devices | | Average or mean operation time, min | Average intraoperative blood loss, mL |
|---|--|---------------------------------|---------------|-------------------------------------|---------------------------------------|
| | | Glisson sheath | Hepatic veins | | |
| Weiss <i>et al</i> ^[23] | 9 | (-) | (-) | - | - |
| Hu <i>et al</i> ^[26] | 18 | (+) | (+) | 105 ± 23 | 75 ± 18 |
| Machado <i>et al</i> ^[27] | 8 | (+) | (+) | 68 | < 100 |
| Tan <i>et al</i> ^[29] | 5 | (+) | (+) | 133.6 ± 29.5 | 230.0 ± 148.3 |
| Shetty <i>et al</i> ^[33] | 4 | (-) | (+) | 193.8 ± 50.0 | 487.5 ± 201.6 |
| Wu <i>et al</i> ^[35] | 9 | (+) | (+) | 205.6 ± 233.2 | 133.3 ± 49.4 |
| Camps Lasa <i>et al</i> ^[36] | 4 | (-) | (+) | 138.8 ± 28.4 | - |
| Zhao <i>et al</i> ^[37] | 4 | (+) | (+) | 107.5 ± 17.1 | 262.5 ± 359.1 |
| Pan <i>et al</i> ^[38] | 3 | (+) | (+) | 101.0 ± 27.6 | 78.3 ± 25.7 |
| Kandil <i>et al</i> ^[41] | 2 | (+) | (-) | 60.5 ± 13.4 | 22.5 ± 10.6 |
| Kim <i>et al</i> ^[42] | 1 | (+) | (-) | 228 | 250 |
| Cipriani <i>et al</i> ^[43] | 13 | (+) | (+) | 195 (125-330) | 175 (100-220) |
| Tzanis <i>et al</i> ^[44] | 1 | (-) | (+) | 110 | 50 |
| Patel <i>et al</i> ^[45] | 1 | (+) | (+) | - | - |
| Dapri <i>et al</i> ^[46] | 1 | (-) | (-) | 96 | 350 |

resection, and the reliability and effectiveness was confirmed^[69-71]. Although staple line reinforcement with the absorbable polymer membrane might increase intraoperative cost, it may eliminate more expensive reoperations associated with staple line hemorrhage and bile leakage, to reduce the final overall cost^[69]. In addition, some other auxiliary methods, such as radiofrequency ablation^[72], could also be helpful for reducing blood loss and improving safety. Certainly, these related designs and modifications, such as application of a suitable laparoscopic articulating liver tissue crushing device, a staple line reinforcement technique with the absorbable polymer membrane or radiofrequency ablation assistance, are still further needed for safe application of stapling devices in open surgery and laparoscopic surgery, and even in SILS. More randomized studies are needed to prove the benefits and find broader indications for the use of stapling devices, to help expand the applications of staplers in liver surgery in the future.

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