



Technical Aspects of Stapled Hepatectomy in Liver Surgery: How We Do It

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Abstract

There are diverse approaches to parenchymal transection and the preferred approach remains controversial among liver surgeons. Stapling devices, which were initially established for vascular control, have been the standard parenchymal transection technique in many departments for more than 15 years. This article describes the technical aspects, tips, and tricks of stapled hepatectomy using right hemihepatectomy as an example. The existing literature on this topic is also reviewed.

Keywords Stapled hepatectomy · Parenchymal transection · Liver resection technique · Endovascular stapler

Introduction

Because of technical progress, liver resection procedures have rapidly evolved in the last decades. However, the preferred technical approach remains controversial within the surgical community. In 1896, Kousnetzoff et al.¹ introduced a method of crushing and ligating the liver vasculature while transecting the parenchyma. To transect the parenchyma more safely, Pringle et al.² developed a way to reduce blood loss by temporarily avoiding the portal blood inflow. In 1952, Lortat et al.³ performed a right hemihepatectomy after isolated vascular control of the right pedicle. Both techniques dramatically reduced blood loss during liver resection.

Nowadays, a variety of techniques are used for parenchymal transection, including cavitron ultrasonic surgical aspiration (CUSA, Cavitron Corp, USA.), water jet (Helix Hydro-Jet®; Erbe Elektromedizin GmbH, Germany), monopolar and bipolar electrocautery, and an electrothermal bipolar vessel sealing system (Ligasure, Medtronic plc, Ireland). All of these techniques reduce bleeding during liver resection and the technical progress is reflected by a postoperative morbidity rate of

4 to 40% and mortality rates between 0 and 5% after major liver resection.^{4, 5}

Another approach for parenchymal transection uses vascular staplers (Ethicon, Inc., USA; Medtronic plc, Ireland). Initially established for vascular control, using stapling devices is a standard parenchymal transection technique in many hospitals and has been used for more than 15 years in our department.^{6, 7} Staplers offer various advantages, such as faster transection, easy handling, and reduced blood loss. Some reports have also described the cost effectiveness of this approach, but this remains controversial.⁸ Like other transection methods, despite the beneficial effects, stapled hepatectomy has a learning curve that is defined by proper handling of the device, correct placement of the stapler into the tissue, and adequate transection.⁹

In this article, we describe the technical aspects, tips, and tricks of stapled hepatectomy in a right hemihepatectomy model and discuss the published literature on this topic. Furthermore, to investigate the safety of stapled hepatectomy, we present the short-term surgical outcomes of a series of patients that received stapled right hemihepatectomy in our center. Our aim is to share our experiences of hepatectomy and what we have learned.

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Methods and Subjects

We extracted and analyzed the data of adult patients who consecutively underwent stapled right hemihepatectomy

performed by three different attending hepatobiliary surgeons as the first (responsible) operator (total $n = 90$, 30 consecutive cases for each surgeon). To evaluate the safety of stapled hepatectomy and to assess the learning curve, further data were extracted: patient characteristics, indication of hepatectomy, intraoperative blood loss, red blood cell (RBC)/fresh-frozen plasma (FFP) transfusion, operation time, postoperative complications, hospital stay, and 90-day mortality.

Technical Aspects of Stapler Use in Right Hemihepatectomy

Stapler use is described in Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10a, b. For resection, the liver is accessed by a right subcostal incision with midline extension, followed by intraperitoneal exploration to exclude disseminated disease. After initial mobilization of the falciform ligament, the liver is fully separated from the triangular and coronary ligament connecting the liver and diaphragm. Intraoperative ultrasound within the parenchyma localizes all suspected tumor nodules and identifies the portal vein and the liver veins. After this, the retrohepatic inferior vena cava is prepared. Starting inferiorly, the cava is freed from the short hepatic and caudate veins and the Makuuchi ligament is transected either with a clip or vascular stapler (Fig. 1). The right hepatic vein is fully exposed and marked with a vessel loop (Fig. 2) before antegrade cholecystectomy and temporary closure of the cystic duct with a bulldog clamp. Next, the hepatoduodenal ligament is exposed and the right pedicle is explored by lowering the hilar plate. Dissection of the vascular branches is optional (Fig. 3). The right liver pedicle and the right hepatic vein are transected by stapling (Fig. 4). The demarcation line is identified between segments 4 and 5/8 (Fig. 5).

Parenchymal dissection is started by crushing the parenchyma with a straight vascular clamp (Fig. 6). The crushed parenchyma is transected with a 45 mm or 60 mm vascular stapler. In our experience, an average of six to ten stapler reloads is required for transection, depending on the liver size.⁴ During positioning of the stapler into the compressed parenchyma, high resistance, and big bites should be avoided

Fig. 1 Preparation and mobilization of the right liver. Short hepatic veins from the inferior vena cava are clipped and transected

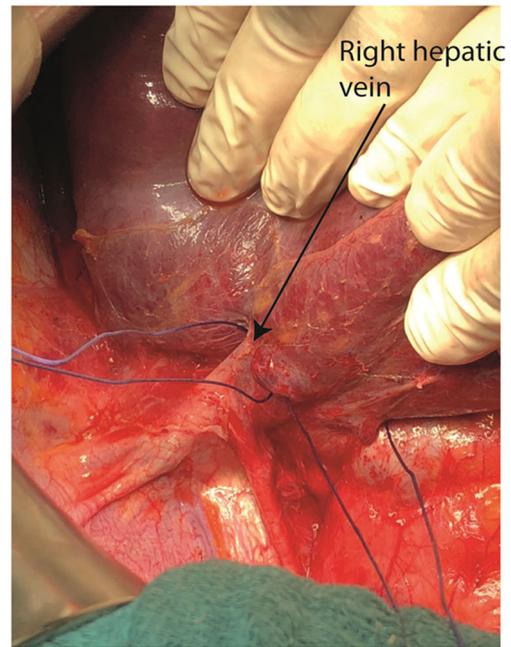
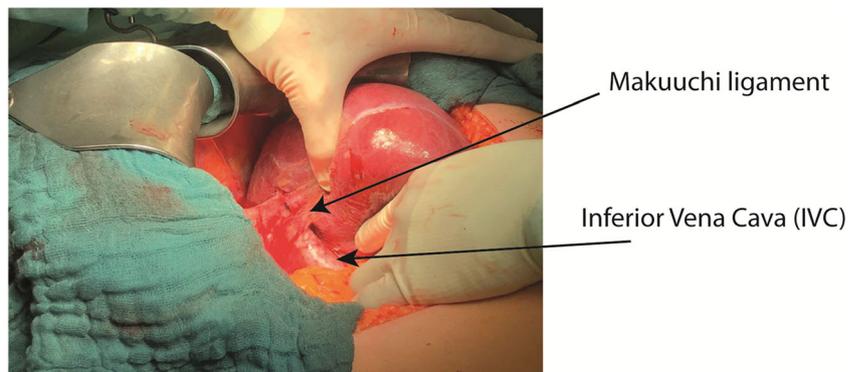


Fig. 2 Exposition and marking of the right hepatic vein

(Fig. 7). It is also important to slowly close the instrument with controlled pressure. The device should be stabilized by the surgical assistant to avoid possible deviation (Fig. 8). The procedure is continued in alternating fashion (Figs. 9 and 10a, b). After hemihepatectomy (Figs. 11 and 12), a White test with Lipofundin (B. Braun Melsungen AG, Germany) is performed by retrograde flushing over the remaining cystic duct and obstruction of the main hepatic duct to detect and close the bile leakage at the transection surface (Fig. 13). The transection surface is hemostased by coagulation with an argon beamer and bipolar cautery (Fig. 14). To prevent torsion of the remaining left liver, the falciform ligament is fixed to the abdominal wall.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., released 2013,

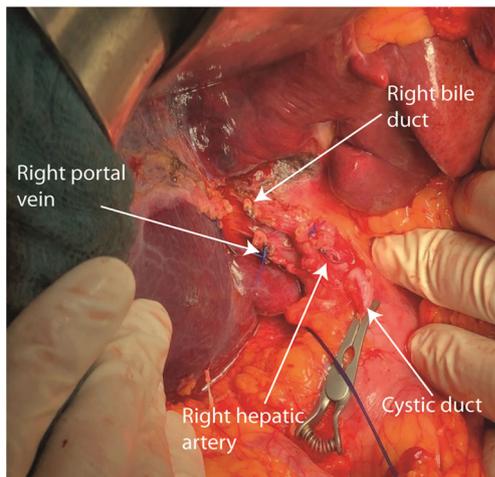


Fig. 3 Exposition of the right pedicle and ligation, and transection of the right hepatic artery, right portal vein, and right hepatic duct

Armonk, NY). Categorical data are expressed as percentages. Continuous variables are shown as means \pm standard deviations. To evaluate improvements in operation time with increasing experience, we analyzed the operation times of the first 90 stapled right hemihepatectomies, which consecutively performed by three different surgeons as the first (responsible) operator. A two-tailed *p* value of less than 0.05 was considered statistically significant in all analyses.

Results

Assessment of Safety

Baseline characteristics, surgical variables, and postoperative outcomes of patients are summarized in Table 1. The mean age of patients was 56.2 ± 12.9 years and 48 patients (53.3%) were male. Metastatic liver diseases were the most common indication for liver resection (66.7% of patients). In all cases, central venous pressure was kept under 5 mmHg during the parenchymal transection. In 37 patients (41.1%), the Pringle

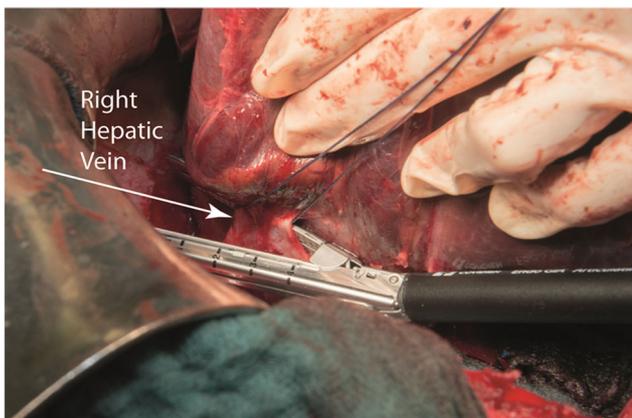


Fig. 4 Dissection of the right hepatic vein with a 45-mm vascular stapler

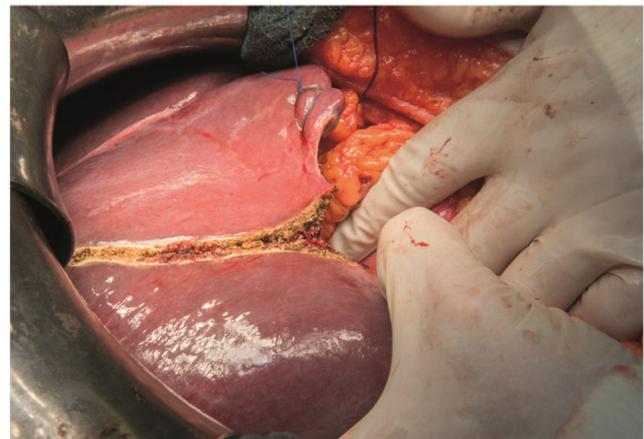


Fig. 5 Marking of the identified demarcation line between segments 4 and 5/8 with electrocautery to determine the resection area

maneuver was used during the liver transection. Mean and median intraoperative blood loss was 777.0 ± 686.2 ml, 500.0 (150–1350) ml, respectively; 19 patients (21.1%) received an RBC transfusion and nine patients (10.0%) received an FFP transfusion during the surgery. Mean operation time was 170.0 ± 63.4 min. Postoperative complications were detected in 36 patients (40.0%), and 90-day mortality in five patients (5.6%).

Learning Curve

As shown in Fig. 15, the mean operation time significantly decreased ($p = 0.009$) as the number of previous stapled hemihepatectomies performed by the surgeon increased. After the first 15 operations by each surgeon, the mean operation time reached a plateau, which remained steady for the next 15 operations for each surgeon. Similarly, the range of standard error of the means also decreased as the number of performed stapled hemihepatectomies increased. This indicates reduced fluctuation and increased stability in operation time as surgical experience increases.

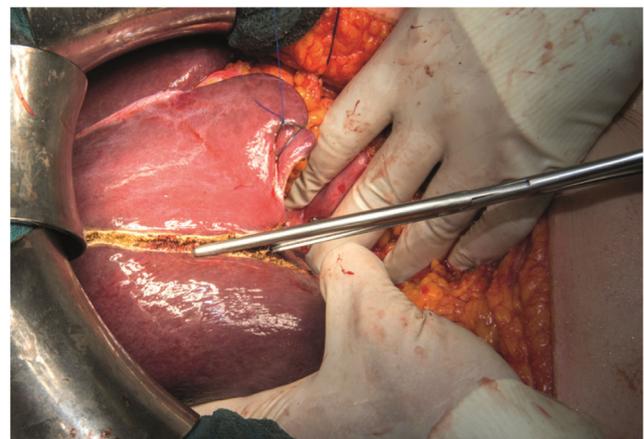


Fig. 6 Start of the transection phase by compressing the parenchyma with a vascular clamp

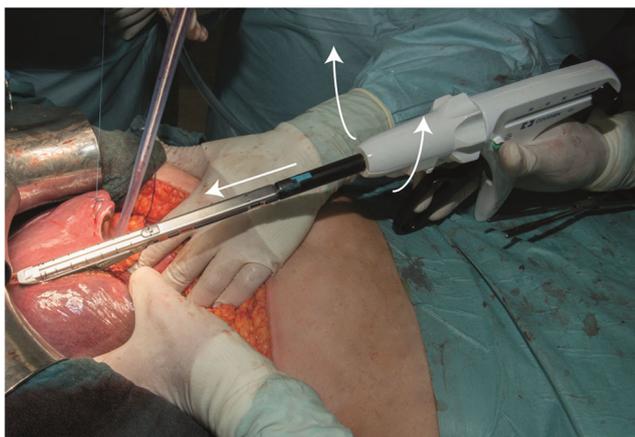


Fig. 7 Positioning of the vascular stapler using rotating movements

Discussion

Surgical training enables residents to learn and perform procedures under the guidance and supervision of trained surgeons. Every surgical procedure has its own learning curve, which even skilled surgeons have to undergo.¹⁰ Hepatopancreatobiliary (HPB) surgeries are demanding operations and require knowledge of the underlying diseases, meticulous surgical skills, and a good clinical infrastructure that offers adequate postoperative management.¹¹ A skilled HPB surgeon needs excellent theoretical and practical training.¹² To be a HPB fellow, the surgeon has to perform 100 major HPB operations, and at least 25 of these need to be performed as the first (responsible) operator.¹³ In this study, we presented an illustrated description of stapled right hemihepatectomy and analyzed the safety and learning curve of this method.

Major hepatic resections are demanding surgical interventions. Multiple reports have associated intraoperative blood loss with higher morbidity rates, impaired patient survival, and a shorter disease-free interval.^{14–17} Almost 30 years ago, Bismuth et al.¹⁸ introduced total vascular exclusion to avoid blood loss by clamping the hepatic in- and outflow. However,

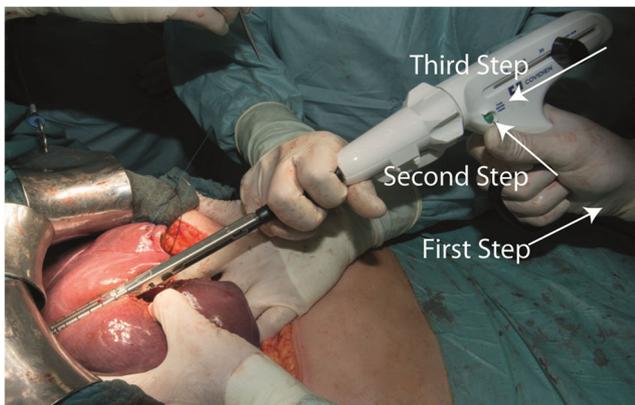


Fig. 8 Firing of the vascular stapler, while the assistant stabilizes the instrument with their hand



Fig. 9 Dissected area after the first stapler launch

this was associated with ischemia reperfusion injury and impaired postoperative recovery.¹⁹ Later, it was shown that particular patients (those suffering from reduced liver function after chemotherapy or with impaired parenchyma due to non-alcoholic steatohepatitis or cirrhosis) are highly susceptible to liver injury and postoperative liver failure.²⁰ In this context, vascular staplers have offered new opportunities for safe liver transection.

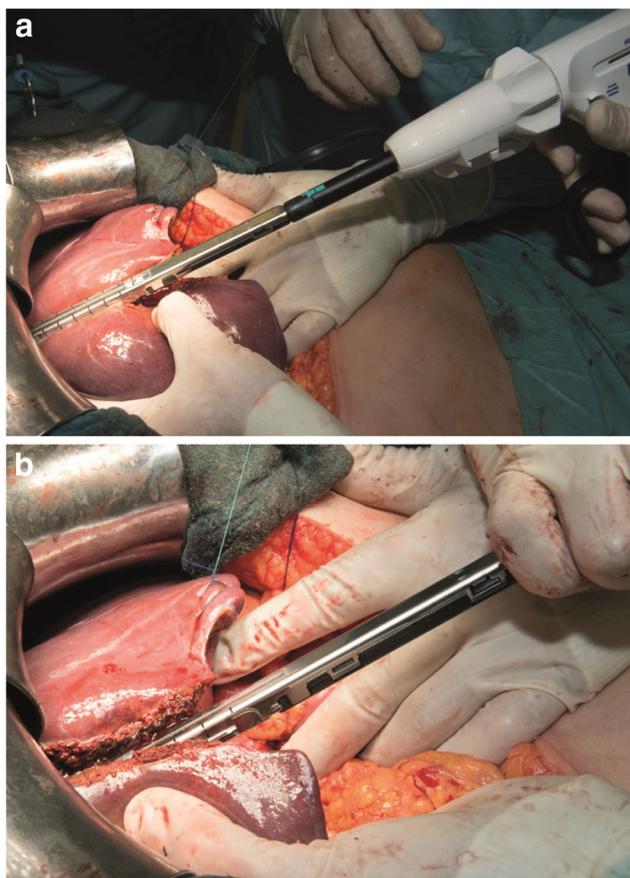


Fig. 10 a, b Continuation of the parenchymal transection



Fig. 11 Resected specimen with the resected area

Initially recommended for small liver resections or laparoscopic surgery, staplers were gradually introduced to major hepatic resections.^{21, 22} A study of 300 patients undergoing major ($n = 193$) and minor ($n = 107$) liver resections with an endo-GIA™ stapler in our center showed similar mortality and morbidity rates with this technique compared with other high-volume centers. Additionally, the median blood loss was 700 ml, even though the Pringle maneuver was only used in 10% of cases.⁷ Balaa et al.²³ published a series of 101 patients undergoing right hemihepatectomy with staplers. The transection speed of the entire lobe was less than 10 min. Furthermore, they demonstrated the safety of stapled hepatectomy with



Fig. 12 Resected right lobe with liver metastases

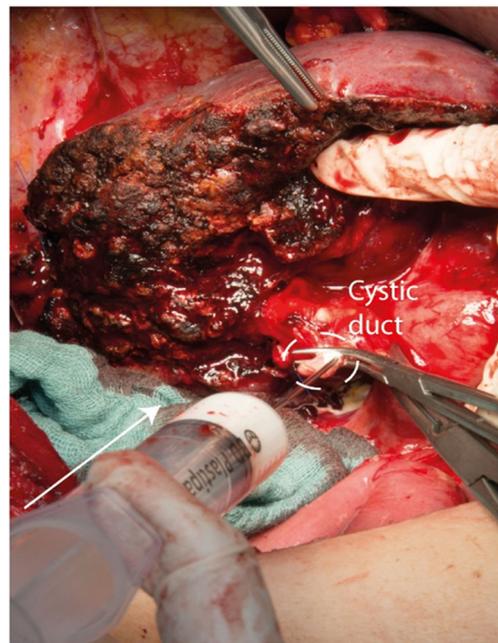


Fig. 13 White test with Lipofundin to check for possible bile leakage

considerably low rates of morbidity and mortality. In this study, the Pringle maneuver was used in all cases, but the Pringle time was reduced. Delis et al.²⁴ reported a median blood loss of 260 ml in 62 patients receiving liver resection with a stapler without using the Pringle maneuver. These results are particularly important in the context of posthepatectomy liver failure, where blood loss is an important risk factor.²⁵

Studies have investigated whether the patient outcome after stapled hepatectomy is similar to other resection techniques. In a single-center cohort study, Riediger et al.⁴ found no differences in operation time, ICU stay, morbidity, and mortality following minor or major hepatectomies using the stapler, water jet, or electrocautery techniques. Savlid et al.²⁶ compared stapled hepatectomies and CUSA in a randomized controlled cohort study. They observed no differences in blood loss, operating time, bile leakage, and total morbidity between the groups. The results of stapled hepatectomy in this study

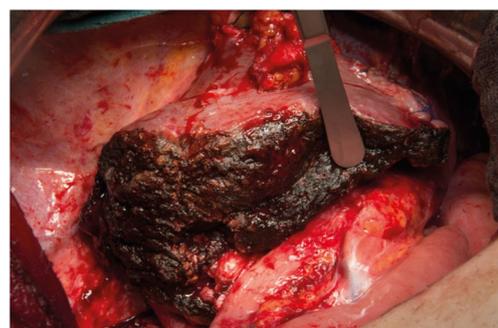


Fig. 14 Resected area after final hemostasis

Table 1 Clinicopathologic characteristics of patients

Variables	<i>n</i> (%) or mean ± SD Total (<i>n</i> = 90)
Age (years)	56.2 ± 12.9
Sex	
Female/male	42/48
BMI (kg/m ²)	25.4 ± 3.7
ASA score	
Class 1	2 (2.2)
Class 2	50 (55.6)
Class 3	38 (42.2)
Indication of hepatectomy	
Benign liver disease	11 (12.2)
Primary malignancy	19 (21.1)
Metastatic disease	60 (66.7)
Pringle maneuver	37 (41.1)
Intraoperative blood loss (ml)	
Mean ± SD	777.0 ± 686.2
Median (i.q.r.)	500 (150–1350)
Transfusion of RBC	
Patient	19 (21.1)
Unit	0.6 ± 1.3
Transfusion of FFP	
Patient	9 (10.0)
Unit	0.3 ± 1.0
Operation time (min)	170.0 ± 63.4
Postoperative complications	36 (40.0)
Hospitalization (days)	14.9 ± 10.3
90-day mortality	5 (5.6)

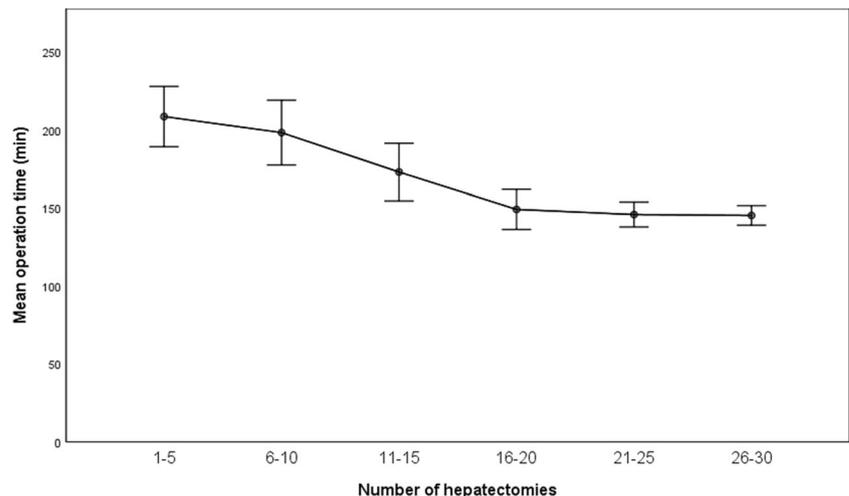
SD, standard deviation; *i.q.r.*, interquartile range; *BMI*, body mass index; *ASA*, American Society of Anesthesiologists; *RBC*, red blood cells; *FFP*, fresh-frozen plasma

are comparable with findings from other transection methods that were presented in previous randomized clinical trials from

our center.^{6, 27} Intraoperative blood loss (mean, 777 ml; median, 500 ml) was lower compared with both clamp-crushing (median, 925 ml)⁶ and Ligasure (mean, 1101 ml)²⁷ transection methods. Mean operation time (170 min) was also shorter in the present study than clamp-crushing (221 min) and Ligasure (199 min) methods. In patients undergoing stapled hepatectomy, intraoperative blood loss can occur because of oozing from the transected liver surface and/or uncontrolled injuries to the middle hepatic vein branches. Furthermore, total morbidity was detected in 40% of patients and 90-day mortality in 5.6% of patients in the present study, which are similar to results of clamp-crushing (morbidity, 46%; mortality, 3%) and Ligasure (morbidity, 39%; mortality, 7%) groups. These findings support that stapled hepatectomy is as safe as other transection methods. Additionally, Rahbari et al.⁶ demonstrated lower blood loss during transection (200 ml to 400 ml), shorter transection time (9 min to 30 min), and shorter duration of portal triad clamping (7 min to 23 min) in the stapler group. Moreover, there were no differences in bile leakage or grade B/C posthepatectomy liver failure between the two groups. Interestingly, the shorter transection time may have an impact on the inflammatory immune response. Schwarz et al.²⁸ described lower IL-6 and CRP levels in patients undergoing stapled hepatectomies compared with CUSA. However, the clinical benefits remain to be fully elucidated.

In this study, we also demonstrated that the mean operation time, as an indicator of the learning curve, significantly decreased as the number of performed stapled hepatectomies increased. Surgeons achieved a plateau with a stable range of mean operation times after performing 15 hepatectomies. This is the same as the reported learning curve of CUSA, which was assessed in living donor liver resection.²⁹ However, the learning curve of CUSA hepatectomy in this report was assessed in both minor and major hepatectomies (left lateral sectorectomy and left and right hepatectomy). It has also been shown that the number of required cases to achieve learning curve increases as the extent of resection

Fig. 15 The mean operation times in relation to the number of previous stapled right hemihepatectomies performed by three different surgeons. Error bars show the standard error of the means



increases.³⁰ This shows that stapled hepatectomy is easy and quick to learn.

Cost is another important factor. Schemmer et al.⁷ reported an operation cost of 5197 EUR for stapled hepatectomy and a total cost of 11,382 EUR for hospitalization. The total hospitalization cost was 2400 EUR cheaper following stapled hepatectomy compared with CUSA. Riediger et al.⁴ calculated a similar operation cost of 5097 EUR for stapled hepatectomy, but reported no cost benefit of the stapler method for major or minor hepatic resection. In fact, they declared stapled hepatectomy the most expensive method. However, this cost analysis focused on the operation only and did not consider hospitalization as a whole; the authors concluded that further calculations should be considered. In the same year, Buell et al.⁹ showed a cost advantage of 13,000 USD for laparoscopic stapled hepatectomy when reduced operating time was taken into consideration. These findings show that the cost effectiveness of stapling devices remains controversial and highlights the need for further research into the economic advantage of this technique. However, evaluating how complications relate to one resection technique or another and how they influence cost effectiveness is difficult. The different training and preferences of individual surgeons may also be influential and should be taken into account.

Conclusions

Stapled hepatectomy has evolved as a safe technique for minor and major hepatic resections showing similar results compared with other established transection techniques. The rates of postoperative complications and mortality after this standardized stapled hepatectomy technique were acceptable and comparable with those of other transection methods reported in the literature. This method is easy to learn and has a short learning curve (the mean operation time plateaued after 15 stapled hepatectomies were performed). According to the results of this study and those of the reviewed literature, stapled hepatectomy is safe and can reduce transection time, blood loss (even without the Pringle maneuver), and manageable costs.

Author Contributions The manuscript was conceived and designed by Mehrabi, Hoffmann, and Nagel. The literature was acquired and reviewed by Nagel, Ghamamejad, Khajeh, Golriz, and Hoffmann. The manuscript was drafted by Nagel, Ghamamejad, Khajeh, Golriz, and Hoffmann and critically revised by Büchler and Mehrabi. Final approval for publication of this manuscript has been given by all authors.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflicts of interest.

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