Surgical Endoscopy (2019) 33:145–152
https://doi.org/10.1007/s00464-018-6285-y

A novel very simple laparoscopic hepatic inflow occlusion apparatus for laparoscopic liver surgery

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Received: 15 December 2017 / Accepted: 18 June 2018 / Published online: 25 June 2018

Abstract

Background Control of bleeding is extremely important for laparoscopic liver resection. We introduce a new and operationally simple laparoscopic hepatic inflow occlusion apparatus (LHIOA) and its successful application in laparoscopic surgery for patients with cirrhosis.

Methods The self-designed LHIOA was constructed using a tracheal catheter (7.5#) and infusion set. The tracheal catheter and infusion set were trimmed to 30 and 70 cm, to serve as an occlusion tube and occlusion tape, respectively. After establishment of pneumoperitoneum, the occlusion tape was inserted to encircle the hepatoduodenal ligament. The occlusion tube was then introduced and the ends of the occlusion tape were pulled out of it to occlude the hepatic inflow. Under intermittent vascular occlusion with the LHIOA, the liver parenchyma was transected using an ultrasonic scalpel and monopolar electrocoagulation. Outcomes of the application of the LHIOA in hepatocellular carcinoma patients with cirrhosis (LHIOA group, $n=46$) were compared with patients undergoing laparoscopic hepatectomy without LHIOA (non-LHIOA group, $n=46$), using one-to-one propensity case-matched analysis.

Results The LHIOA effectively occluded the hepatic inflow while showing no damage to the hepatoduodenal ligament. The time required for presetting the LHIOA is 6.8 ± 0.6 min. The conversion rate in the non-LHIOA group was 13.0% while there was no conversion in the occlusion group ($P<0.001$). The median blood loss of patients in the LHIOA group (60 ml, range 50–200 ml) was significantly less than that of patients in the non-LHIOA group (250 ml, range 100–800) ($P<0.001$). Transfusion was required in 8 patients in the non-LHIOA group while no transfusion was required in the LHIOA group. The median operative time in the LHIOA group (157 min, range 80–217 min) was significantly shorter than that in the non-LHIOA group (204 min, range 105–278 min) ($P<0.001$).

Conclusions The new LHIOA is effective, safe, and simple. It can significantly reduce conversion rate, blood loss, and operative time. It facilitates laparoscopic liver resection and is recommended for use.

Keywords Laparoscopy · Liver surgery · Hepatic inflow occlusion · Cirrhosis · Hepatocellular carcinoma · Propensity case-matched analysis

Abbreviations

HCC	Hepatocellular carcinoma
LHIOA	Laparoscopic hepatic inflow occlusion apparatus

Hepatic inflow vascular occlusion is one of the most important techniques in liver surgery [1]. The role of vascular occlusion, including Pringle's maneuver, appears to be decreasing with improved transection techniques [2–4]. However, it remains an important and useful technique in reducing bleeding from inflow vessels. This technique is particularly necessary for conducting liver surgery in patients with abnormal liver parenchyma (such as cirrhotic or steatotic liver). Most hepatocellular carcinoma (HCC) cases in

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Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00464-018-6285-y) contains supplementary material, which is available to authorized users.

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China are associated with hepatitis B virus (HBV) infection, and the patients often present with liver cirrhosis. In addition, in recent years, patients presenting with steatotic liver have become more common as cases of obesity increase. Therefore, resection of HCC is often performed in patients with cirrhotic or steatotic liver. Furthermore, this technique is also particularly necessary for long and complicated operations, and mass blood loss, especially when the operations are performed by surgeons who are not experienced in liver resection.

In recent years, the laparoscopic technique has been increasingly used for liver surgery and is gaining acceptance worldwide. Hepatic inflow occlusion is especially important in laparoscopic liver surgery because the hemostasis during liver transection is not as easy as that in open surgery. Suction for minor bleeding cannot be used permanently. Hepatic inflow occlusion allows the surgeon to reliably control bleeding and perform a meticulous transection [5]. However, hepatic inflow occlusion is not easy to perform in laparoscopic liver resection, although it is relatively easy in open surgery. During laparoscopic surgery, there are only trocars connecting the peritoneal cavity and extraperitoneal space. Reproduction of the technique used in open liver resections has proved to be difficult.

In this study, we employ a new self-designed, very simple to operate, and convenient laparoscopic hepatic inflow occlusion apparatus (LHIOA) and have shown its successful application in laparoscopic liver surgery. The effectiveness and safety of the new apparatus were evaluated. The outcomes of the LHIOA application in HCC patients with cirrhosis were compared with patients who underwent laparoscopic hepatectomy without the LHIOA, using a one-to-one propensity case-matched analysis.

Materials and methods

This study was performed in accordance with the ethical guidelines of the 1975 Declaration of Helsinki and was approved by the Ethics Committee of Zhongshan Hospital of Fudan University. Written informed consent was obtained from all patients.

Laparoscopic hepatic inflow occlusion apparatus

The new self-designed LHIOA is composed of an occlusion tube and an occlusion tape (Fig. 1). The occlusion tube was created from tracheal tube (Portex, 7.5 mm, Smiths Medical, USA) used for anesthesia. The cross head and balloon of the tracheal tube were removed. The tube was trimmed to 30 cm to serve as an occlusion tube (Fig. 1). The occlusion tape was created from infusion sets (KDL, China). The tube of the infusion sets was trimmed to 70 cm to be used as an occlusion tape. The occlusion tube and occlusion tape were assembled and formed the LHIOA (Fig. 1). All the manipulations mentioned above followed aseptic principles. After establishment of pneumoperitoneum, a 1.2-cm trocar was placed 5–8 cm below the xyphoid (Fig. 2). The

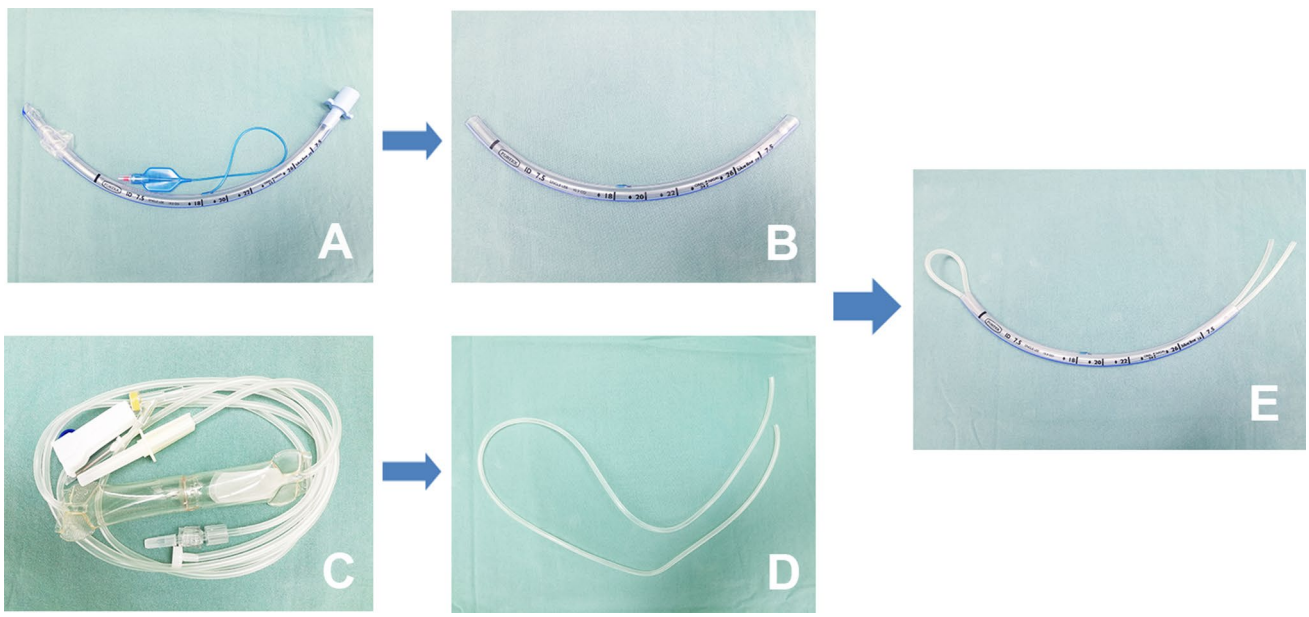

Fig. 1 The novel self-designed LHIOA is made using a tracheal catheter (7.5#) and infusion set. The cross head and balloon of the tracheal catheter are removed and the tube is trimmed to 30 cm to serve as an occlusion tube. The infusion set is trimmed to 80 cm to be used as an occlusion tape. The occlusion tube and occlusion tape constitute the LHIOA

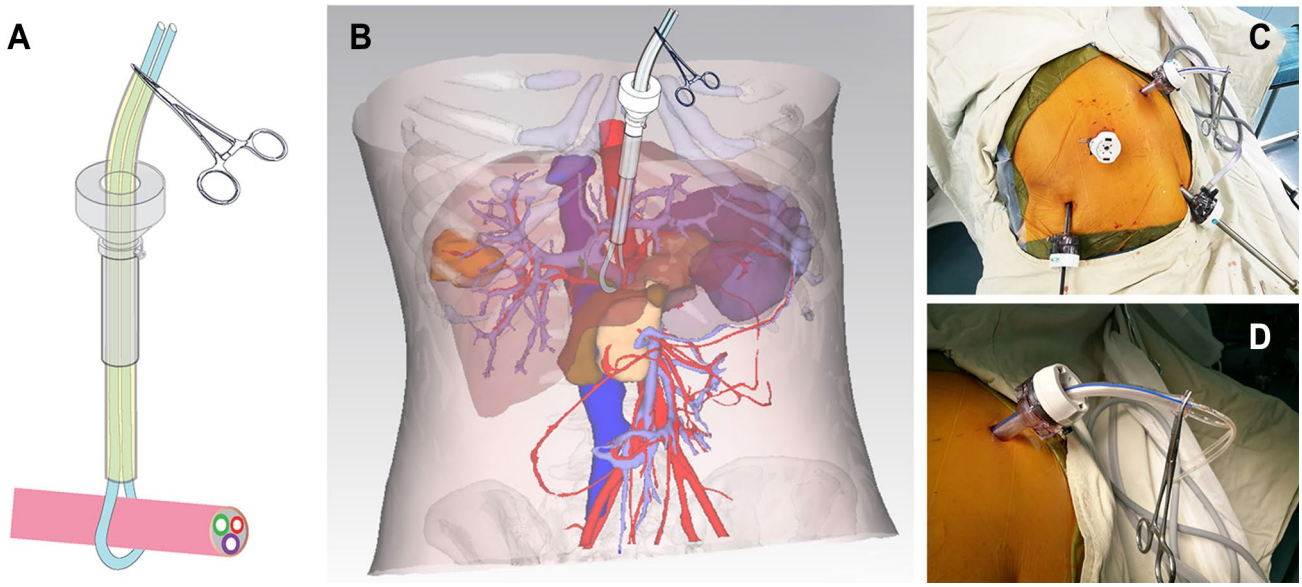

Fig. 2 Illustration of the LHIOA. **A, B** Diagram of the LHIOA. The occlusion tape is introduced to encircle the hepatoduodenal ligament (pink). The occlusion tube is inserted and the occlusion tape is pulled out through it to occlude the hepatic inflow. The portal triad clamping is fixed with a forceps. **C, D** Extracorporeal view of the LHIOA (exemplified by a patient undergoing VI/VII bisegmentectomy)

lesser omentum was opened with a Harmonic scalpel. The occlusion tape was introduced into the peritoneal cavity and placed around the hepatoduodenal ligament from the foramen of Winslow (Fig. 3). The occlusion tape was placed from right to left to encircle the hepatoduodenal ligament for left hepatectomy (Fig. 3A–F). When a trocar at the right midaxillary line of the abdomen is available for right hepatectomy, the forceps can directly enter into the lesser omentum through the trocar and the occlusion tape can be easily pulled from left to right to encircle the hepatoduodenal ligament (Fig. 3G–L). After placement of the occlusion tape, the occlusion tube was inserted (Figs. 2, 3E, L). The occlusion tape was pulled out through the occlusion tube and then the LHIOA was ready for use (Fig. 3F, L). When inflow occlusion was needed, the occlusion tube was pushed inside and the occlusion tape tightened until the inflow signal disappeared as monitored by color Doppler ultrasound (Fig. 4). After the hepatic inflow was totally occluded, the occlusion tape was fixed with a hemostatic forceps (Fig. 2). In operations that require multiple occlusions, intermittent vascular occlusion was applied with 15-min clamping and 5-min releasing.

Propensity score-matched case–control study of clinical application

Propensity score-matched analysis was conducted to evaluate the difference in perioperative outcomes in patients undergoing laparoscopic liver resection with or without the LHIOA. From August 2013 to August 2017, 279 consecutive laparoscopic liver resections for initial treatment of single HCC were conducted in Zhongshan Hospital Fudan University. The patients were divided into two groups according to the use of LHIOA (LHIOA group and non-LHIOA group). Propensity score matching was used at a 1:1 ratio to correct differences in the demographics and clinical factors in the two groups. Ninety-two HCC patients were paired through the propensity score matching conditional on liver cirrhosis (METAVIR score), type of hepatectomy (anatomical/non-anatomical), extent of hepatectomy, tumor location, Child–pugh score, prothrombin time, platelet count, and coagulation index (by thromboelastography). All covariates that were chosen for the model were determined by a priori analysis showing clinical relevance. Perioperative treatments were undertaken with the same maneuver in each group except intraoperative use of LHIOA. All the operations were performed by the same surgery team who are experienced in laparoscopic liver surgery. Anatomical hepatectomy was preferred while partial hepatectomy was only used when the tumor was located in segment VII/VIII. Liver parenchymal transection was performed using an ultrasound scalpel (Harmonica, Ethicon) and monopolar electrocautery (Velleylab) under intraoperative ultrasound guidance. Small vessels were directly dissected with the ultrasound scalpel, clipped with Hem-a-lok clips or electrocoagulated by monopolar electrocautery. Large vascular and biliary vessels were transected using a linear vascular endostapler (Ethicon) as necessary. Suture hemostasis was performed if necessary. In the occlusion group, parenchymal transection was performed under intermittent hepatic inflow

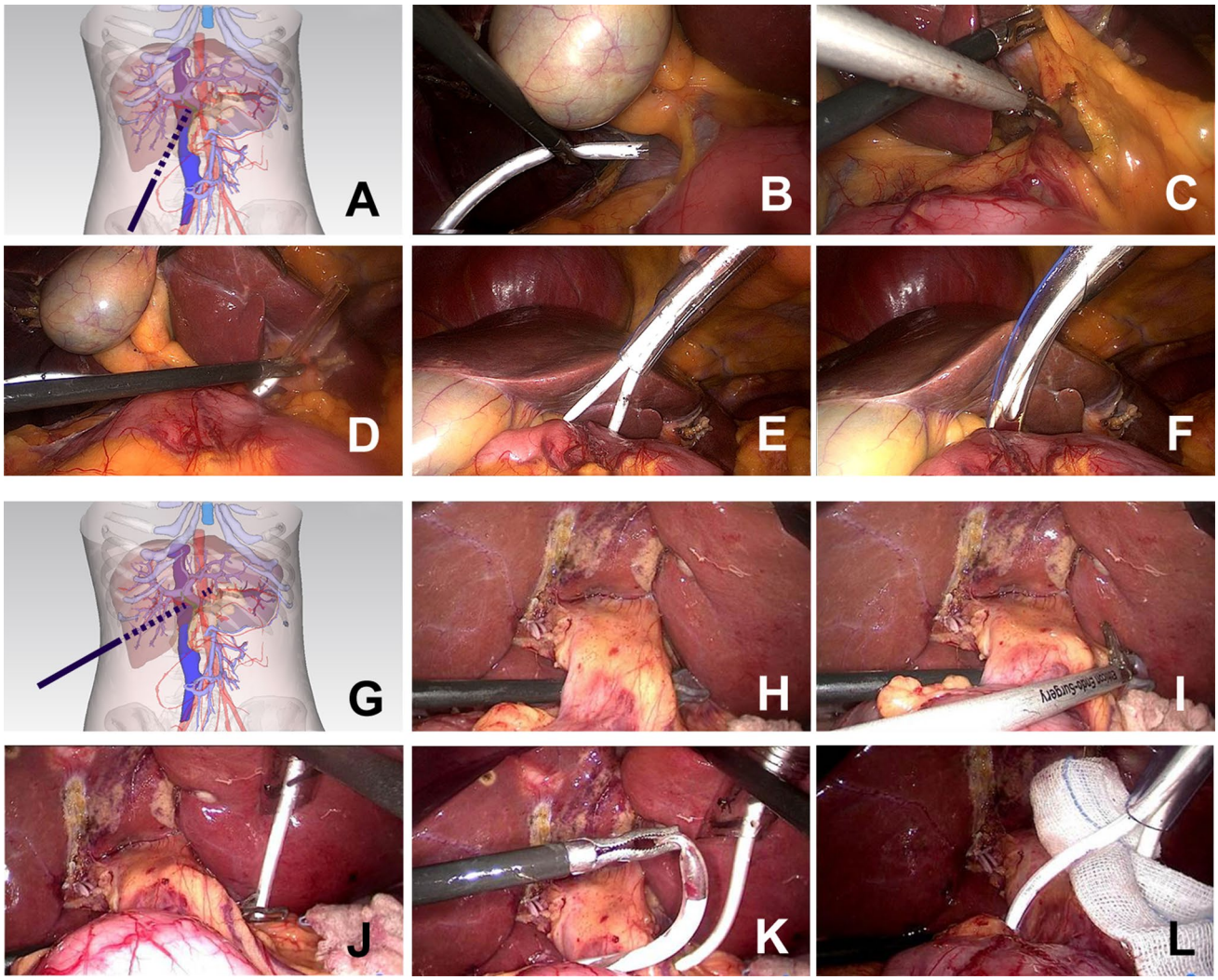

Fig. 3 Application of the LHIOA. **A**–**F** Presetting of the LHIOA in left hepatectomy. The occlusion tape is introduced into the lesser sac through the foramen of Winslow. The lesser sac is lifted and opened with an ultrasonic scalpel. The occlusion tape is pulled up to encircle the hepatoduodenal ligament. The occlusion tube is inserted and the occlusion tape is pulled out through it to occlude the hepatic inflow. **G**–**L** Presetting of the LHIOA in right hepatectomy (exemplified by a case with gallbladder removed). A trocar at the right midaxillary line is used (blue line). A forcep is directly introduced into the lesser sac to grasp the occlusion tape and pull it from left to right to encircle the hepatoduodenal ligament after the lesser sac is opened

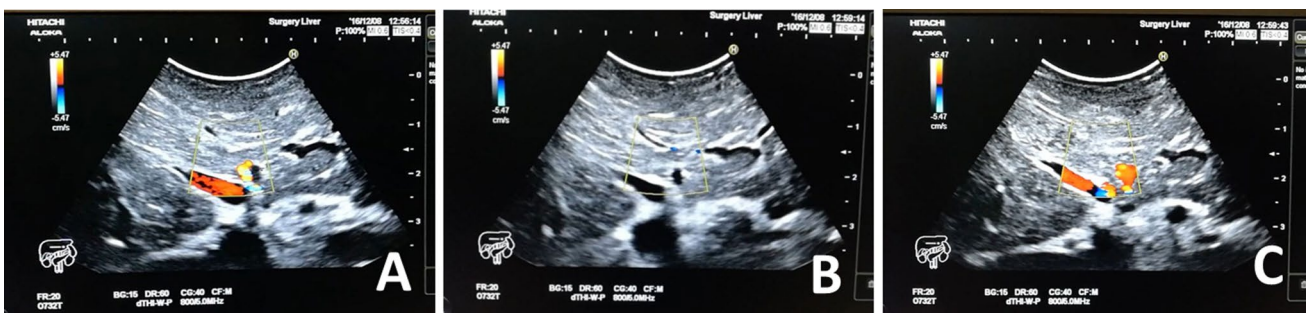

Fig. 4 Intraoperative laparoscopic color doppler flow imaging shows thorough occlusion of hepatic inflow after applying the LHIOA. **A** Inflow blood flow is clearly observed before application; **B** no blood flow from portal vein and artery can be observed after application. Only blood flow from hepatic vein can occasionally be detected; **C** after release of the LHIOA, the blood flow is restored immediately

occlusion using the LHIOA with 15 min of clamping and 5 min of unclamping. During all the operations, the intraoperative fluid infusion was restricted to reduce the central venous pressure (CVP). The extraction of specimens was performed using a plastic bag through a Pfannenstiel incision. The blood loss, operative time, duration of liver parenchyma transection, changes of postoperative liver function, and complications were compared.

Statistical analysis

All the continuous values were expressed as the median (range) and categorical data were expressed as numbers or frequency. Comparison between groups was examined using a non-parametric test (Wilcoxon Signed Rank Test) for the continuous parameters and a McNemer χ^2 test for categorical parameters. All statistical analyses were performed with software package SPSS 22.0 (IBM SPSS, USA). Statistical significance was defined as $P < 0.05$.

Results

The new laparoscopic hepatic inflow occlusion apparatus is effective, safe, and very simple to operate

The new LHIOA can effectively occlude the hepatic inflow. Doppler ultrasound showed that it can thoroughly occlude the hepatic inflow, including arterial and portal venous flow (Fig. 4). The thorough hepatic inflow occlusion, in combination with the low central venous pressure (CVP) technique, can create a bloodless operative field and considerably reduce intraoperative blood loss (Fig. 5). Liver parenchyma can be easily transected using only an ultrasonic scalpel and a monopolar-coagulation device. The Glisson sheath and main hepatic vein could be elaborately dissected (Fig. 5). The new LHIOA significantly reduced the difficulty of liver parenchyma transection and made challenging and complex liver surgery feasible in patients with abnormal parenchyma (cirrhotic or steatotic liver). The time required for presetting the LHIOA is 6.8 ± 0.6 min (5.8 ± 0.6 min in cases of right hepatectomy with the aid of the right midaxillary line trocar and 7.3 ± 1.3 min in cases of left hepatectomy without the aid of the right midaxillary line trocar) (Fig. 3). The new LHIOA is safe and is well tolerated in all patients. The median number of laparoscopic intermittent clamping using the LHIOA was 3.4 times (range 1–5) in patients receiving hepatic inflow occlusion. It had no general hemodynamic effect and no specific anesthetic management was required. The follow-up investigation showed no damages to the hepatoduodenal ligament. There was no localized edema of the hepatoduodenal ligament, thrombosis of artery or the portal vein, and cholangitis or obstructive jaundice. A postoperative liver function investigation showed that hepatic inflow occlusion with the LHIOA did not increase hepatic damage when compared with those patients without use of the LHIOA (Supplementary file S1). Additionally, the new LHIOA is very simple to use and easy to construct. All the components of the LHIOA are available in all standard operation rooms and do not need additional preparatory work, such as sterilization, before surgery (Fig. 1).

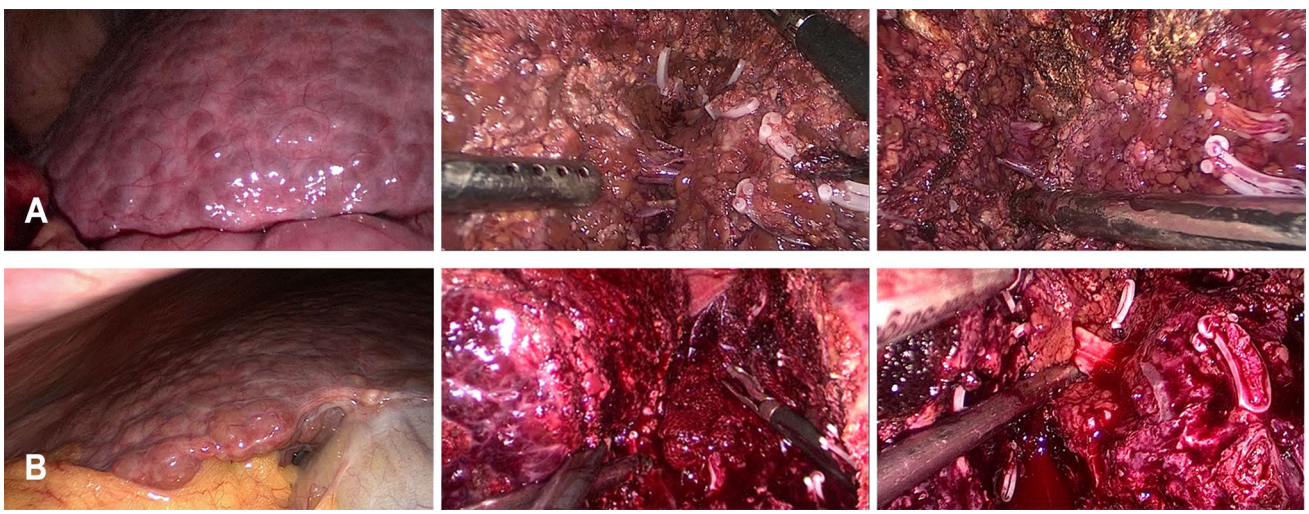

Fig. 5 Liver parenchymal transection with or without the LHIOA in patients with cirrhosis. **A** With the LHIOA. Bloodless operative field is created and meticulous division is achieved. Vessels are clearly exposed and elaborately dissected. Intraoperative blood loss is significantly less; **B** Without the LHIOA. Cirrhotic liver is inclined to bleed. Operative field is often unclear and liver transection is difficult

The LHIOA facilitates laparoscopic liver surgery and makes complex surgery feasible in patients with cirrhosis

A total of 92 HCC patients with cirrhosis underwent laparoscopic liver surgery. There was no significant difference in demographic data between the LHIOA group ($n=46$) and non-LHIOA group ($n=46$). All the variables, including METAVIR score, type of hepatectomy, extent of hepatectomy, tumor location, prothrombin time, platelet count, and coagulation index (thromboelastography) were well balanced in both groups. The conversion rate in the non-LHIOA group was 13.0% (6/46). Hepatectomy with a large transection surface in HCC patients with cirrhosis was associated with massive bleeding, which often resulted in conversion. Six of the 10 cases of VI/VII bisegmentectomies without LHIOA were converted to open laparotomy due to massive uncontrollable bleeding. The minor resection (such as IV unisegmentectomy) was conducted with acceptable bleeding. However, liver transection using conventional devices (ultrasonic scalpel and monopolar electrocoagulation device) is still challenging. The new LHIOA greatly facilitated laparoscopic surgery in patients with cirrhosis and made difficult surgery feasible. With the help of LHIOA, all the procedures in the HCC patients with cirrhosis were completed laparoscopically. There was no conversion in the LHIOA group (0/46). All of the procedures were completed using only an ultrasonic scalpel and monopolar electrocoagulation device. The blood loss and operative time in the LHIOA group were significantly less than those in the non-LHIOA group (Table 1). The median blood loss in the LHIOA group was 60 ml (range 50–200) while in the non-LHIOA group it was 250 ml (range 100–800) ($P<0.001$). Transfusion was required in 8 patients in the non-LHIOA group, whereas no one in the LHIOA group required it (Table 1). The median operative time in the LHIOA group was 157 min (range 80–217), while that of the non-LHIOA group was 204 min (range 105–278) ($P<0.001$). The time for liver parenchyma transection in the LHIOA group was 71 min (range 20–110), while in the non-LHIOA group it was 107 min (range 45–185). Six patients in the non-LHIOA group developed postoperative ascites. No postoperative complications were observed in the LHIOA group and all the patients had a quick postoperative recovery. The median length of hospital stay was 5 (5–7) days and 5 (5–12) days in the LHIOA group and non-LHIOA groups, respectively ($P=0.014$) (Table 1).

Table 1 Perioperative results of HCC patients with cirrhosis who undergo laparoscopic liver surgery with or without the new LHIOA

	LHIOA group	non-LHIOA group	*P*
Conversion (%)	0% (0/46)	13.0% (6/46)	<0.001
Blood loss (ml)	60 (50–200)	250 (100–800)	<0.001
Transfusion (*n*)	0% (0/46)	17.4% (8/46)	<0.001
Operative time (min)	157 (80–217)	204 (105–278)	<0.001
Time of liver parenchyma transection (min)	71 (20–110)	107 (45–185)	<0.001
Complications (*n*)			
Ascites	0	6	<0.001
Bile leakage	0	0	–
Bleeding	0	0	–
Hospital stay (days)	5 (5–7)	5 (5–12)	0.014

Discussion

In this study, a new and very simple LHIOA was employed. Our data showed that the novel LHIOA was effective, safe, and convenient for use. It provided thorough and satisfactory hepatic inflow occlusion and good control of intraoperative bleeding. A bloodless operative field was often created and liver transection could be completed rapidly with only an ultrasonic scalpel and monopolar electrocoagulation device. Application in HCC patients with cirrhosis showed that the LHIOA could significantly decrease the intraoperative blood loss and operative time.

Laparoscopic liver resection is still a demanding operation, even if it is performed by experienced liver surgeons. A major challenge is bleeding during liver parenchymal transection. Bleeding can obscure views and make surgery difficult, occasionally necessitating conversion to an open procedure. This is obvious in patients with abnormal parenchyma (cirrhotic or steatotic liver). The massive blood loss can be life threatening and its necessitating blood transfusion increases the risk of postoperative morbidity, mortality, and tumor recurrence [6, 7]. Therefore, the laparoscopic approach is often reserved for these patients. A safe performance and expansion of laparoscopic liver surgery depend on the technological advances that address the management of bleeding and hemostasis [6, 8]. So far, different methods have been used to decrease blood loss during liver resection. Hepatic inflow occlusion is one of the main strategies [9]. In open laparotomy, inflow occlusion is easily performed. However, it is often difficult to reproduce in a laparoscopic setting [10–12]. To date, laparoscopic inflow occlusion techniques have proved to be successful in only small clinical series and there is still no consensus on standard instrumentation. The techniques can be categorized into three types, including laparoscopic vascular clamp, cable-tie tourniquet, and bulldog vascular clamps [13–16]. Each technique has its advantages and drawbacks. The choice of occluding instrumentation is mainly based on the surgeon anecdotal experiences of surgeons. The laparoscopic bulldog clamps (such as endo intestinal clips) produce significantly less clamping

force than cable-tie tourniquet-based devices and thus allow greater flow across the clamped segment; this can translate into poorer intraoperative hemostasis. The handheld vascular clamps generate higher force than bulldog clamps. However, the occlusive capabilities of vascular clamps appear to be quite variable and its placement often hinders the manipulation [16, 17]. At present, the most common application is to use a self-made occlusion apparatus which is based on the tourniquet technique originally applied in cardiovascular surgery. The principle of the tourniquet technique is very simple, but a suitable material for this technique is not easy to find. Components that have been employed in the apparatus vary greatly. The occlusion tapes include umbilical tape, sling, tetron tape, and nylon tape [5, 6, 18–22]. The occlusion tube can consist of a urinary catheter, latex tube, or thoracic drainage tube with varying degrees of hardness [5, 6, 18–22]. The tapes reported are lacking in elasticity and are not easy to pass behind the hepatoduodenal ligament. Specific instrumentation (such as Roticulator Endo Grasp and Endo Retractor Maxi) is often required to introduce the tape [10, 18, 19, 23]. An additional problem associated with these tapes is the potential "cutting effect" on the portal triad, which is one of the greatest concerns. The non-elastic tapes potentially cause hepatoduodenal ligament damage, which may be more significant when multiple occlusions are performed during operation. We chose an infusion set tube as occlusion tape to improve it. The infusion set tube can be easily placed with no requirement for the use of specific instruments (Fig. 3). It is elastic and can self-adapt into flat broadband that can distribute pressure evenly on the hepatoduodenal ligament when it is applied to squeeze the portal triad. Intraoperative observation under laparoscope and postoperative follow-up investigations show no damage to the hepatoduodenal ligament. Another concern is the ischemic-reperfusion injury to the liver parenchyma, especially in patients with cirrhosis. This study shows that intermittent laparoscopic clamping using the LHIOA is well tolerated. It does not lead to increased damage to cirrhotic livers, which is consistent with that in open laparotomy [5]. Furthermore, another advantage is that the LHIOA is very easily accessible. All the components of the LHIOA (tracheal tube and infusion sets) are available in standard operating rooms. They are all sterile and require no additional preoperative preparation (such as sterilization). It takes not more than 10 min to assemble and preset. One drawback of our LHIOA is that the occlusion is fixed extracorporeally. An additional trocar is needed and it sometimes hinders manipulation. Further study is required to improve it to allow for intracorporeal fixation.

Laparoscopic liver surgery in patients with cirrhosis is still challenging due to significantly increased bleeding, especially in complex liver surgery in which the transection surface area is large. Intraoperative uncontrollable bleeding often results in conversion to open laparotomy, even when using an advanced transection device such as a cavitron ultrasonic surgical aspirator (CUSA). Vascular control is particularly important for these patient populations [1]. Our study shows that application of the LHIOA can satisfactorily control intraoperative bleeding and facilitates surgery in these patients. With the aid of the LHIOA, laparoscopic resections can be easily completed in patients with cirrhosis by using only conventional instrumentation (ultrasonic scalpel and monopolar electrocoagulation). No conversion was required with the aid of the LHIOA, whereas the conversion rate in patients without using the LHIOA reached 13.0%. The device significantly decreases the difficulty of the liver transection and makes a number of challenging operations feasible. In this study, all 10 cases of VI/VII bisegmentectomy were successfully completed with the aid of the LHIOA, whereas 6 of the 10 corresponding operations were converted to laparotomy due to massive uncontrollable bleeding. The application of the LHIOA can create a "bloodless" operative field and allows for quick liver transection using only an ultrasonic scalpel and monopolar electrocoagulation. As a result, blood loss and operative time are significantly reduced for patients with cirrhosis. As patients with cirrhosis clearly benefit from this technique, the new LHIOA is strongly recommended for routine use in these patients, especially for inexperienced surgeons, complex operations, or laparoscopic surgery with simple transection devices.

In conclusion, this study provides a new LHIOA which greatly facilitates laparoscopic hepatectomy in liver parenchyma transection. The LHIOA can significantly reduce intraoperative blood loss and operative time of laparoscopic liver surgery. It is effective, safe, simple, and easily reproducible. It is strongly recommended for use in laparoscopic liver surgery, especially for patients with cirrhosis.

Acknowledgements We thank David Duchenne, Jenny Xu, Susan Zhao, and Hua Young for editorial assistance and language improvement.

Author contributions YP, YS: Study concept and design; YP, FC: acquisition of data; YP, FC, ZW, YS: analysis and interpretation of data; YP: drafting of the manuscript; YS: critical revision of the manuscript for important intellectual content; YP, ZW: statistical analysis; YP, YS: obtained funding; JZ, JF: administrative, technical, or material support; and JF: study supervision.

Funding This work was supported by the grants from National Natural Science Foundation of China (No. 81572296) and Zhongshan Science & Technology Innovation Fund (2015).

Compliance with ethical standards

Disclosures Yuanfei Peng, Zheng Wang, Xiaoying Wang, Feiyu Chen, Jian Zhou, Jia Fan, and Yinghong Shi declare no conflict of interest.

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