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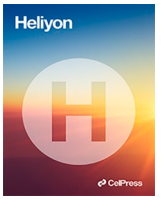

Research article

A novel Pringle maneuver instrument for laparoscopic hepatectomy

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ABSTRACT

Background: The Pringle maneuver is a classic and commonly used technique in hepatectomy for bleeding control. However, it is not convenient to perform Pringle maneuver in laparoscopic hepatectomy. This study aimed to investigate the value of a novel blocking forceps designed by our center for the Pringle maneuver in laparoscopic hepatectomy.

Methods: Data of patients with liver tumors who underwent laparoscopic hepatectomy between 2017 and 2022 were retrospectively collected. Patients who underwent an intraoperative Pringle maneuver were selected. Cases using the new blocking forceps comprised the new blocking forceps group (NBF group), while cases using the traditional method of binding the hepatoduodenal ligament comprised the traditional group (TRA group). The baseline and perioperative data of the two patient groups were compared and analyzed.

Results: A total of 253 cases were included in the analysis, including 169 in the TRA group and 84 in the NBF group. There were no statistically significant differences between the two groups in terms of preoperative examinations and other indicators. The NBF group had a significantly lower number of blocks, total blocking time, intraoperative bleeding, and transfusion ratio than the TRA group.

Conclusion: Our self-designed blocking forceps can safely and effectively complete the Pringle maneuver and are convenient to operate, which is conducive to the successful completion of the operation.

1. Introduction

Hepatectomy is a common treatment for liver disease. Since the development of hepatectomy, laparoscopic hepatectomy has become increasingly widespread [1–3]. Control of intraoperative bleeding, especially during laparoscopic hepatectomy, is crucial. Blockage of blood flow to the liver is an important technique for controlling bleeding. The most classic method is blocking the first portal, that is, the Pringle maneuver, which has been widely used in hepatectom [4]. However, there are some shortcomings in the use of the traditional Pringle maneuver in laparoscopic hepatectomy. First, performing the Pringle maneuver is time consuming and laborious, especially for laparoscopic resection. Second, when using the traditional Pringle method to block the first hepatic portal, the degree of the block cannot be precisely controlled; this may damage the bile duct walls. Third, When tightening or relaxing the

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Abbreviations:

ICG-R15	indocyanine green retention rate at 15 min
HbsAg	hepatitis B surface antigen
anti-HCV	hepatitis C virus antibody
AFP	alpha-fetoprotein
CEA	carcinoma embryonic antigen
CA	carbohydrate antigen
TB	total bilirubin
ALT	alanine aminotransferase
AST	aspartate aminotransferase
PT	prothrombin time
ALB	albumin
NBF	new blocking forceps
TRA	traditional

blocking, the visual field of the lens should focus on the first hepatic porta. The surgical site could not be considered at the same time. It is not safe, especially during bleeding. In addition, it causes ischemia/reperfusion injury [5,6].

To control blood flow into the liver more effectively during laparoscopic hepatectomy and overcome the disadvantages of the traditional Pringle method, our medical center designed blocking forceps to perform the Pringle maneuver more easily and effectively during laparoscopic hepatectomy. This study investigated the convenience and effectiveness of the blocking forceps.

2. Materials and methods

2.1. Patients

The case data of patients with hepatic disease treated with laparoscopic hepatectomy at the First Affiliated Hospital of Wannan Medical College (Yijishan Hospital) were retrospectively collected between January 2017 and June 2022. The inclusion criteria were as follows: 1) underwent laparoscopic hepatectomy after preoperative evaluation; 2) the first hepatic portal block was taken; and 3) preoperative liver function rating Child–Pugh classification A with an indocyanine green retention rate at 15 min (ICG-R15) $\leq$15 %. The exclusion criteria included missing imaging or clinical data. This study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Institutional Review Board. The requirement for written informed consent was

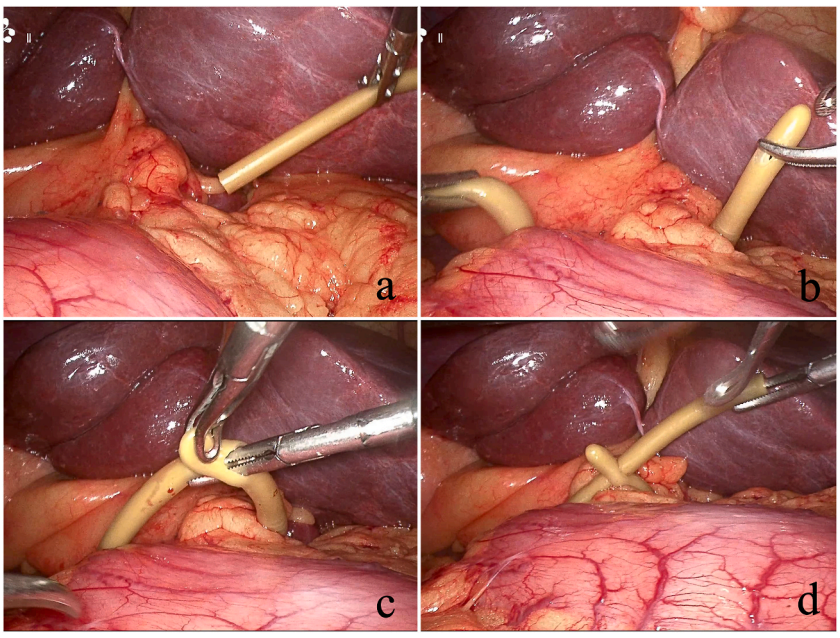

Fig. 1. Classical pringle maneuver for laparoscopic hepatectomy a/b) The 10-gauge Fuchs' ureter was passed posteriorly through the hepatoduodenal ligament from the lesser omentum; c/d) The hepatoduodenal ligament was subsequently tied by the ureter.

waived due to the retrospective nature of the study. The Ethics Committee of Yijishan Hospital of Wannan Medical College approved this study.

The following statistics were collected for all patients: 1) general demographic data, including age, sex, height, and weight; 2) laboratory tests for hepatitis B surface antigen (HbsAg), hepatitis C virus antibody (anti-HCV), alpha-fetoprotein (AFP), carcinoma embryonic antigen(CEA), carbohydrate antigen (CA)19-9, total bilirubin (TB), alanine aminotransferase (ALT), aspartate aminotransferase (AST), prothrombin time (PT), albumin (ALB), and ICG-R15; 3) preoperative imaging data of the location, size, whether the tumor invaded the blood vessels, and whether it was associated with cirrhosis; 4) number of first portal blocks, block time, operation time, blood loss, blood transfusion, conversion to an open abdomen, R0/R1/R2 resection status, and minimum incision margin; and 5) postoperative complications, time to first postoperative flatus, postoperative hospital stay, and mortality.

2.2. Blocking method

Patients using the novel blocking forceps designed independently by our center for the Pringle maneuver were defined as the new blocking forceps group (NBF group). Other cases in which cotton rope or silica rubber catheter binding was used for the hepatoduodenal ligament were defined as the traditional group (TRA group). Regardless of the blocking method, the principle adopted for blocking was the 15-5 approach (i.e., each block should last no more than 15 min with at least 5 min between each block).

2.3. Classical pringle blocking (TRA group)

During this procedure, the hepatoduodenal ligament was dissected and the lesser omental sac was opened. A laparoscopic vascular clamp was passed posteriorly through the hepatoduodenal ligament from the lesser omentum, and a 10-gauge Fuchs ureter was clamped and passed posteriorly through the hepatoduodenal ligament. The hepatoduodenal ligament was subsequently tied. When the first hepatic portal block was performed, the ureter was tied tightly. Fig. 1(a–d).

2.4. New blocking clamp method (NBF group)

A small 0.5 cm incision was made at the intersection of the left anterior axillary line and the two transverse fingers below the left costal arch. Extracorporeal blocking forceps were then used. One side of the front end of the blocking forceps was placed behind the hepatoduodenal ligament, and the jaws were closed enough to establish the first hepatic portal block. Our external blocking forceps feature seven gears. The first gear was closed to fix the blocking forceps without blocking blood flow. When the seventh gear was closed, about 95 % of hepatic hilar blood flow was blocked based on intraoperative ultrasound monitoring of hepatic blood flow. Fig. 2 (a–d), Fig. 3(a–c). And the trocars position with the forceps are shown in Fig. 4(a and b).

2.5. Statistical analysis

Statistical analysis was performed using SPSS 22.0. The *t*-test was used for the comparison of normally distributed measures, and the rank sum test was used fr non-normally distributed measures. Count data were compared using the $\chi 2$ test or Fisher's exact probability, and $P < 0.05$ was considered a statistically significant difference.

3. Results

A total of 253 patients, including 179 men and 74 women, underwent laparoscopic hepatectomy and met the screening criteria. All

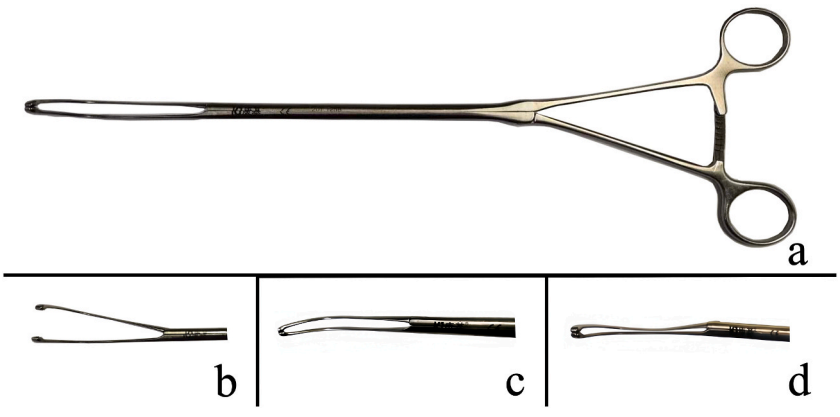

Fig. 2. The blocking forceps a) A holistic view of the forceps; b) The state in which the forceps is open; c) The forceps was closed with the first gear; d) The forceps was closed with the seventh gear.

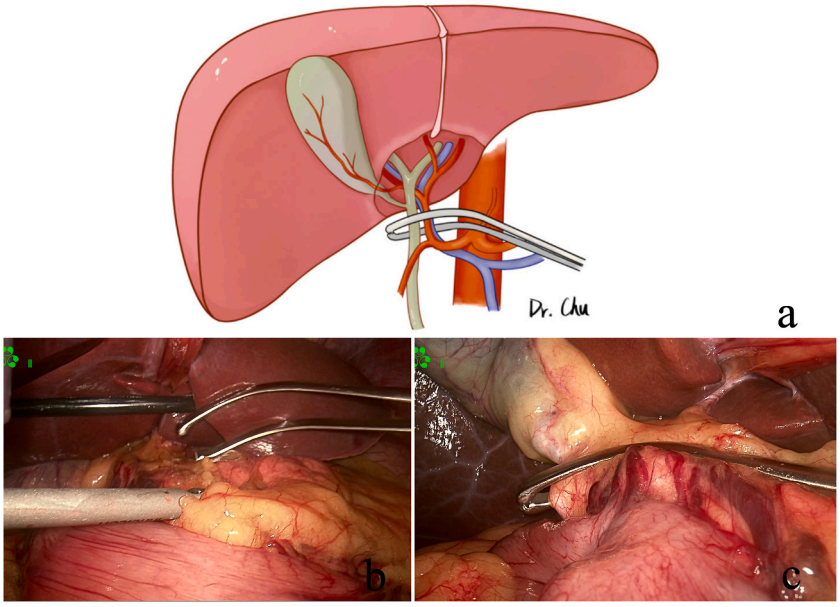

Fig. 3. The blocking forceps for pringle maneuver a) The schematic diagram of forceps for pringle maneuver (drawn by author Chu Hongpeng); b) One side of the front end of the forceps was placed behind the hepatoduodenal ligament from the lesser omentum; b) The first gear was closed to just fix the blocking forceps without blocking blood flow.

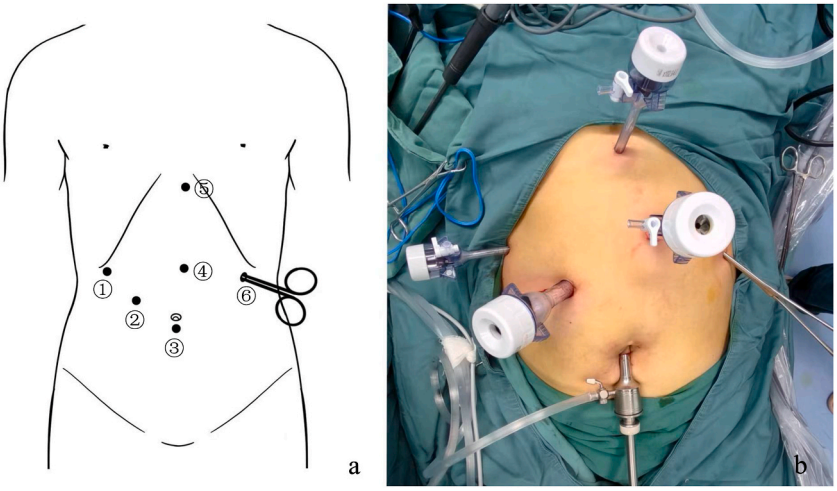

Fig. 4. The trocars position with the forceps a) Schematic diagram of puncture locations ①below the right rib margin and along midclavicular line; ②between first and third locations; ③below the navel; ④between first and fifth locations; ⑤below the xiphoid; ⑥the intersection of the left anterior axillary line and the two transverse fingers below the left costal arch. b) Intraoperative photograph of trocar sites.

patients had preoperative liver function with an ICG-R15 < 15 %. 233 patients of the 253 had a preoperative liver function rating of Child–Pugh class A. Another 20 cases were class B at the time of the initial diagnosis, which were turned to class A. There were 114 HbsAg positive and 9 hepatitis C virus antibody positive patients. 134 patients were combined with cirrhosis. The extent of liver resection included 88 cases in the left lobe, 40 cases in the middle lobe, and 125 cases in the right lobe. 214 cases of malignant tumors were diagnosed by postoperative pathology, including 149 cases of hepatocellular carcinoma, 52 cases of intrahepatic cholangiocarcinoma, 5 cases of mixed cell carcinoma, 7 cases of liver metastasis from colon cancer, and 1 case of neuroendocrine carcinoma. There were 39 cases of benign disease, including 17 cases of hepatic hemangioma, 20 cases of intrahepatic choledocholithiasis, and 2 cases of focal nodular hyperplasia (Details are presented in Table 1).

There were 169 and 84 patients in the TRA and NBF groups, respectively. There were no statistically significant differences between the two groups in terms of preoperative examination results and other indices. There was no statistically significant difference between the two groups in terms of the duration of the operation or the proportion of conversions to opening. The times of intraoperative

Table 1
Baseline characteristics of 253 patients underwent laparoscopic hepatectomy associated with Pringle maneuver.

Characteristics	TRA Group n = 169	NBF Group n = 84	*P* value
Sex			0.295
Male	116	63	
Female	53	21	
Age(years)	65(54, 70)	64(52, 72)	0.727
Height (meter)	1.65(1.6, 1.7)	1.68(1.6, 1.7)	0.283
Weight(kg)	60(55, 68)	63(56, 70)	0.161
BMI	22.54 ± 3.31	22.96 ± 2.85	0.323
HbsAg			0.193
Positive	81(47.9 %)	33(39.3)	
Negative	88(52.1)	51(60.7)	
Anti-HCV			1.000
Negative	163 (96.4 %)	81 (96.4 %)	
Positive	6 (3.6 %)	3 (3.6 %)	
Cirrhosis			0.083
Yes	96 (56.8 %)	38 (45.2 %)	
No	73 (43.2 %)	46 (54.8 %)	
Child-Pugh grade			0.751
A	155 (91.7 %)	78 (92.9 %)	
B	14 (8.3 %)	6 (7.1 %)	
Preoperative laboratory tests			
ICG-R15	5.6 (3.4, 8.5)	6.1 (4.65, 10.1)	0.121
ALB(g/L)	40.5 (37.80, 43.40)	40.15 (35.65, 44.73)	0.988
AFP(ng/ml)	4.37 (2.57, 93.20)	5.06 (2.80, 148.91)	0.510
CEA(ng/ml)	3 (1.93, 4.77)	2.58 (1.80, 4.43)	0.144
CA199(U/L)	9.17 (4.30, 28.93)	12.7 (6.51, 34.00)	0.093
ALT(U/L)	22 (16, 37)	27 (17, 49)	0.117
AST(U/L)	26 (21, 37)	28 (20, 41)	0.568
TB(umol/L)	14.52 (10.31, 20.38)	15.81(11.33, 24.26)	0.158
PT(s)	12.1 (11.4, 13.1)	12.3 (11.6, 13.2)	0.504
Extent of liver resection			0.133
Right lobe	91 (53.8 %)	34 (40.5 %)	
Left lobe	54 (32 %)	34 (40.5 %)	
Middle lobe	24 (14.2 %)	16 (19 %)	
Diagnosis			0.134
Malignant tumors	147 (87 %)	67 (79.8 %)	
Benign disease	22 (13 %)	17 (20.2 %)	

Values are expressed as mean ± SD, P50 (P25, P75) or number (percentage). BMI, Body Mass Index; HBsAg, hepatitis B surface antigen; Anti-HCV, hepatitis c virus antibody; ICG-R15, indocyanine green retention rate at 15 min; ALB, albumin; AFP, alpha fetoprotein; CEA, carcinoma embryonic antigen; CA 19-9, carbohydrate antigen 19-9; ALT, alanine aminotransferase; AST, aspartate aminotransferase; TB, Total bilirubin; PT, Prothrombin time.

blocking and the total duration of blocking in the NBF group were significantly lower than those in the TRA group. The number of times was 2(1,4) and the duration of blocking was 30(15,60) min in the NBF group, while in the TRA group, it was 3(2,5) and 45(30,75) min, respectively. In terms of intraoperative bleeding, blood loss in the NBF group was lower than that in the TRA group (200(50,400) ml vs 200(100,400) ml, respectively, P = 0.048). The percentage of transfusions in the NBF group (15.5 %) was significantly lower than that in the TRA group (29.6 %). R0 resection was achieved in all the surgeries (Details are presented in Table 2).

In terms of postoperative indicators, there were no significant differences in the incidence of complications and PT on postoperative day 3. However, postoperative ALT, AST, and TB indices were lower in the NBF group than in the TRA group. The postoperative times to first flatus, drainage tube removal, and length of hospital stay were also shorter in the TRA group. No perioperative mortalities were

Table 2
Intraoperative data.

Characteristics	TRA Group n = 169	NBF Group n = 84	*P* value
Duration of operation (min)	240 (180, 330)	256 (172.5, 360)	0.470
Blood loss (ml)	200 (100, 400)	200 (50, 400)	0.048
Patients required transfusion			0.015
Yes	50 (29.6 %)	13 (15.5 %)	
No	119 (70.4 %)	71 (84.5 %)	
Conversion			0.893
Yes	17 (10.1 %)	8 (9.5 %)	
No	152 (89.9 %)	76 (90.5 %)	
Times of blocking	3 (2, 5)	2 (1, 4)	0.004
Duration of blocking	45 (30, 75)	30 (15, 60)	0.004

Values are expressed as mean ± SD, P50 (P25, P75) or number (percentage).

observed (Details are presented in Table 3).

4. Discussion

Bleeding control is an important factor in the success of liver resection, especially for laparoscopic hepatectomy. Many reports have shown that intraoperative hemorrhage is the main reason for conversion to open surgery or the failure of surgery [7–9]. Effectively controlling and reducing intraoperative bleeding is crucial for the successful completion of laparoscopic hepatectomy. The classical method for reducing bleeding is blocking the blood flow of the portal vein and hepatic artery into the liver, also known as the Pringle maneuver, which requires strapping the hepatoduodenal ligament [4,10,11]. This can greatly reduce bleeding during dissection of the liver parenchyma. However, it is not convenient to perform Pringle maneuver in laparoscopic hepatectomy.

Pringle maneuvers performed entirely in the abdominal cavity are time-consuming and laborious. Some scholars have reported modified methods, such as the hooking method reported by Zhou [13]. However, this method may be associated with the risk of catheter loosening, which can alter the blocking effect [14]. Some surgeons also use metal blood clips for blocking [10,15], which also pose the risk of intraoperative loosening. When the visual field of the lens was focused on the first hepatic porta for Pringle maneuver entirely in the abdominal cavity, the surgical site could not be taken care simultaneously. It is not safe during operation. For the extracorporeal Pringle maneuver, a common method is to use a cotton thread to bind the hepatoduodenal ligament, which is passed through a thicker tube to the outside of the body [16–18]. With this method, the drainage tube must be placed at a relatively high position to maintain sufficient tension, which affects the surgical field and hinders the operation of other instruments. Some surgeons also propose the use of a long-handle vascular clamp for occlusion; however, this causes intimal damage to the blood vessels and bile ducts. Excessive blocking forces may damage the intima of blood vessels and bile ducts. Some studies have reported the occurrence of hepatic artery aneurysms and portal vein thrombosis [10,12]. Excessive blocking forces is also associated with liver ischemia and long-term occlusion is associated with the risk of hepatic ischemia/reperfusion injury, postoperative liver necrosis, and hepatic failure. These disadvantages lead to some risks in the application of the Pringle maneuver or can even directly affect the prognosis of patients with complications, which limits the application of the Pringle maneuver.

An important reason for the aforementioned drawbacks of the Pringle maneuver is that it cannot accurately control the clamping force. It is difficult to ensure a blocking effect during laparoscopy, and owing to the different operators, the blocking effects may differ. There is a certain degree of subjectivity. Excessive strapping force may lead to 100 % complete occlusion of hepatic blood flow; however, complete occlusion inevitably increases the risk of hepatic ischemia and necrosis, ischemia/reperfusion injury, liver failure, and bile duct injury [19,20]. The actual need may be to reduce the blood flow into the liver to reduce bleeding from the liver. This was sufficient to ensure that bleeding was within a safe and controllable range. It is not necessary to completely block the blood flow to the liver. An insufficient strapping force may lead to insufficient occlusion of hepatic blood flow, resulting in no control of the bleeding. In addition, there is a risk of loosening of the blocking in the traditional method, especially for laparoscopic surgery. Laparoscopic strapping is time-consuming, labor-intensive, and difficult to perform.

The blocking forceps used at our center were designed to overcome the shortcomings of the classic Pringle method. Here, we summarize several features and advantages. First, the blocking forceps had seven gears to quantify the blockage. Intraoperative ultrasonography revealed that 95 % of the blood flowing into the liver was blocked when the seventh gear was closed. This effectively avoids excessive or insufficient blockage using the traditional method. Secondly, the handle of the clamp is located outside the body, making it easy and quick to operate. This procedure can be performed by an assistant. Laparoscopic hepatoduodenal ligament binding is time consuming and labor intensive. And because the handle is outside the abdominal cavity, it is not necessary to move the laparoscopic lens from the surgical area to the hepatoduodenal ligament when the occlusion is performed. The vision of the laparoscopic lens is always focused on the surgical operation area, which can increase safety, especially when bleeding occurs. This is also an important difference from traditional blocking. Third, the front end of the forceps was reserved with space to avoid excessive blockage of the bile duct. The risk of bile duct injury was also reduced. Fourth, compared with other methods, the extracorporeal Pringle maneuver is used because the forceps are metallic and different from the tube. The forceps was placed in the lower position through the abdominal wall. It does not affect vision or the surgical operation. Fifth, our clamp, unlike the long-handled vascular clamp, did not damage the blood vessels. Our statistical data showed that the overall number of blocking times and duration of blocking in the NBF group were significantly lower than those in the TRA group. Intraoperative bleeding and blood transfusion ratios in the NBF group were significantly lower than those in the TRA group. This indicates that the blocking effect of our new forceps is exact, whereas the traditional method cannot accurately control the blocking effect and has a poor blocking effect. Therefore, the amount of bleeding is higher, and the corresponding blocking times and total blocking time are inevitably greater. In terms of postoperative liver function, ALT, AST, and TB levels in the NBF group were lower than those in the TRA group on postoperative day 3, which we believe to be related to the shorter clamping times and less intraoperative bleeding. In terms of postoperative complications, there was no occurrence of liver failure or necrosis of the liver tissue, which we considered to be related to the strict implementation of the 15-5 principle during surgery. Similarly, no hepatic artery aneurysms or portal vein thromboses occurred.

However, there are some disadvantages of using our blocking forceps. Compared with the traditional method of binding to the hepatoduodenal ligament, we need to add an extra puncture hole to the abdominal wall. The post-operative AST and ALT levels on postoperative day 3 were collected, but the recovery curve of which was not observed. As the overall complication rate is relatively low, we did not analyze the relationship between complications and different types of hepatectomies as other researchers have done with liver resection [21].In addition, because it is still in the design and research stage and has not been mass-produced, we did not test the durability of the forceps.

In conclusion, our self-designed hepatic portal blocking forceps can achieve a good blocking effect in laparoscopic hepatectomy for

Table 3
Postoperative data.

Characteristics	TRA Group n = 169	NBF Group n = 84	*P* value
Laboratory tests on postoperative day 3			
ALT(U/L)	234 (161, 345)	186 (120.75, 329.5)	0.047
AST(U/L)	224 (170, 337)	197 (129.25, 315.75)	0.027
TB(umol/L)	21.81 (16.88, 29.45)	20.31 (11.115, 31.172)	0.044
PT(s)	13.9 (12.8, 14.9)	14 (13.1, 15.2)	0.465
Complication	10(5.9 %)	4(4.8 %)	0.931
Clavien-Dindo Classification			0.667
I	5(3 %)	3(3.6)	
II	2(1.2 %)	1(1.2 %)	
IIIa	3(1.8 %)	0(0 %)	
Postoperative time of removing drainage tube (days)	6 (4, 9)	5 (4, 7)	0.034
Postoperative time to first flatus (days)	2 (1, 2)	3 (2, 3)	<0.001
Postoperative hospital stay(days)	8 (6, 11)	6.5 (4, 8)	0.004

Values are expressed as P50 (P25, P75) or number (percentage). Complications graded according to Clavien – Dindo classification.

the Pringle maneuver, which is more convenient and safer than the traditional blocking method and is conducive to the successful completion of the operation.

CRediT authorship contribution statement

Chu Hongpeng: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Wang Yongkai:** Software, Methodology, Data curation. **Shen Zhengchao:** Methodology, Data curation. **Xi Shihang:** Writing – review & editing, Data curation. **Jiang Bin:** Software, Investigation. **Pan Xuan:** Writing – review & editing, Project administration, Conceptualization. **Wang Xiaoming:** Data curation.

Ethical statement

This study was reviewed and approved by Ethics Committee of Yijishan Hospital of Wannan Medical College. No. 2023-194. Informed consent was not required for this study because the retrospective nature of the study.

Data and code availability statement

Data will be made available on request. For requesting data, please write to the corresponding author.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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