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Clinical and economic comparison of laparoscopic versus open hepatectomy for primary hepatolithiasis: a propensity score-matched cohort study

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Background: It is unclear whether laparoscopic hepatectomy (LH) for hepatolithiasis confers better clinical benefit and lower hospital costs than open hepatectomy (OH). This study aim to evaluate the clinical and economic value of LH versus OH.

Methods: Patients undergoing OH or LH for primary hepatolithiasis at Yijishan Hospital of Wannan Medical College between 2015 and 2022 were divided into OH group and LH group. Propensity score matching (PSM) was used to balance the baseline data. Deviation-based cost modelling and weighted average median cost (WAMC) were used to assess and compare the economic value.

Results: A total of 853 patients were identified. After exclusions, 403 patients with primary hepatolithiasis underwent anatomical hepatectomy (OH $n=143$; LH $n=260$). PSM resulted in 2 groups of 100 patients each. Although LH required a longer median operation duration compared with OH (285.0 versus 240.0 min, respectively, $P<0.001$), LH patients had fewer wound infections, fewer pre-discharge overall complications (26 versus 43%, respectively, $P=0.009$), and shorter median postoperative hospital stays (8.0 versus 12.0 days, respectively, $P<0.001$). No differences were found in blood loss, major complications, stone clearance, and mortality between the two matched groups. However, the median overall hospital cost of LH was significantly higher than that of OH (CNY¥52,196.1 versus 45,349.5, respectively, $P=0.007$). Although LH patients had shorter median postoperative hospital stays and fewer complications than OH patients, the WAMC was still higher for the LH group than for the OH group with an increase of CNY ¥9,755.2 per patient undergoing LH.

Conclusion: The overall clinical benefit of LH for hepatolithiasis is comparable or even superior to that of OH, but with an economic disadvantage. There is a need to effectively reduce the hospital costs of LH and the gap between costs and diagnosis-related group reimbursement to promote its adoption.

Keywords: deviation-based cost modelling, hepatolithiasis, hospital cost, laparoscopic hepatectomy, operation duration, postoperative hospital stay

Introduction

Hepatolithiasis is prevalent in the south of China, Japan, and Korea[1]. Although rare in the West, it is becoming more common in some Western countries, including the United States, due to increasing immigration from endemic areas[2]. Hepatolithiasis is characterized by the formation of stones in the intrahepatic bile ducts (IHBD), often accompanied by biliary stricture and extrahepatic stones. Patients present clinically with repeated episodes of acute cholangitis. Over a long period of time, hepatolithiasis can lead to liver fibrosis, liver atrophy, liver abscess, secondary cirrhosis, and even cholangiocarcinoma[3,4], which seriously threatens the health and quality of life of patients. In this case, hepatectomy is

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the most effective and definitive method, which can simultaneously remove the stones and accompanying liver lesions[1,3,5].

For the treatment of hepatolithiasis, open hepatectomy (OH) is the classical approach with recognized safety and efficacy, while robotic-assisted hepatectomy (RH) is used only in a few top medical institutions due to its high cost[6]. With the improvements in laparoscopic techniques and devices, more and more surgeons and patients are opting for laparoscopic hepatectomy (LH) for the treatment of hepatolithiasis in the past 20 years. Many studies compared the outcomes of LH with OH for hepatolithiasis, a relatively consistent finding was the shorter length of stay for LH compared with traditional OH. However, there are currently no international guidelines on LH for hepatolithiasis. In addition, previous studies were almost limited to small samples, selection bias, and simple comparison of single laparoscopic versus open procedure, such as left lateral segmentectomy[7–10], left hemihepatectomy[11–13], left-sided hepatectomy[14–17], right hemihepatectomy[18], and major hepatectomy[19], which cannot accurately reflect the overall picture of LH. Few researches addressed comprehensive comparisons of multiple procedures. Furthermore, the conclusions of these studies regarding operation duration and complication are not completely consistent and even contradictory. Therefore, it is necessary to perform an overall comparison using a large sample, little or no bias, and multiple procedures.

More importantly, none of the previous studies have examined the economic value of LH for hepatolithiasis, and few studies have so far sought to investigate this issue thoroughly. In the modern era of cost control and diagnosis-related group (DRG) payment to hospitals, potentially higher cost of laparoscopic procedures may be a significant barrier to its extensive adoption in the treatment of hepatolithiasis. In fact, concerns have been raised regarding the relative cost-effectiveness of this procedure versus OH for hepatolithiasis. Although some studies have shown that laparoscopic liver resections reduce or do not increase the hospital costs of patients with liver tumours[20–25], it is uncertain whether these conclusions are applicable to hepatolithiasis because it has unique anatomic and pathological features such as abnormal anatomic structures, dense perihepatic adhesions, and multiple stones. Therefore, it is still unclear whether patients undergoing LH incur higher or lower hospital charges than those undergoing open resection.

The aim of the present study was to evaluate the clinical and economic values of LH for primary hepatolithiasis by comparing the outcomes of LH with OH.

Patients and methods

Study design

This study was conducted in accordance with the Declaration of Helsinki and its later amendments, and approved by the Institutional Review Board of Yijishan Hospital of Wannan Medical College (Grant No. [2022]106). The study has been registered in the Chinese Clinical Trial Registry (registration No. ChiCTR2300072545). As this was a retrospective cohort study with anonymized data, no individual informed consent was provided. Patients undergoing anatomical hepatectomy for primary hepatolithiasis at Yijishan Hospital of Wannan Medical College from 1 January 2015, through 31 December 2022, were included and divided into the OH and LH groups. Their clinical data were collected and supplemented from the electronic medical records, imaging database, and outpatient records from 1 January 2021, to 30 June 2023. Subsequently, the data were checked for missing values and discrepancies. The missing values were then imputed. If there was an imbalance in baseline between the two groups, propensity score matching (PSM) was applied[20–22]. In the end, the outcomes were compared. The study design and preparation of the original manuscript were performed according to the Strengthening the Reporting of Cohort Studies in Surgery (STROCSS 2021 Guideline)[26].

HIGHLIGHTS

- The overall clinical benefit of laparoscopic hepatectomy is generally superior or equal to open hepatectomy for primary hepatolithiasis.
- Laparoscopic hepatectomy required higher median hospital costs and weighted average median cost.
- It is necessary to reduce effectively the costs of laparoscopic hepatectomy and the gap between costs and diagnosis-related group reimbursement to promote its adoption in the treatment of hepatolithiasis.

Inclusion and exclusion criteria

Patients were selected from the database in case of (1) proven multiple stones in the IHBD by computed tomography and/or magnetic resonance imaging, with or without concomitant benign liver lesions at the same site as most stones, including liver atrophy, chronic liver abscess, IHBD stenosis or dilation, hepatic hemangioma, IHBD papilloma, etc., (2) a history of cholangitis, with or without a history of biliary surgery, (3) patients with Child-Pugh class A or B and serum albumin greater than 30 g/l, (4) anatomical hepatectomy as the main treatment for hepatolithiasis, or hepatectomy followed by a biliary exploration, (5) typical histological changes of hepatolithiasis confirmed by histological analysis, and (6) patients undergoing simple laparoscopic exploration and subsequent OH were included in the OH group. The following exclusion criteria were used: (1) secondary intrahepatic stones due to anastomotic stenosis of previous biliary-enteric anastomosis, (2) intrahepatic stones combined with intrahepatic cholangiocarcinoma (ICC) or other hepatobiliary malignancy, (3) no any treatment or only drug treatment, (4) pure percutaneous choledochoscopic lithotomy, biliary exploration, or biliary-enteric anastomosis as the main treatment measure for stones, and (5) non-anatomical hepatectomy.

Surgical procedure

After cholangitis was controlled and liver function was improved, all patients underwent elective anatomical hepatectomy under general anaesthesia with tracheal intubation. In the OH group, the liver resection was performed according to the literature report[27].

In the LH group, patients were placed in the supine position with their legs apart. All LHs were performed by senior surgeons who had more than 3 years of experience in laparoscopic liver surgery and had overcome the learning curve of LH. A CO_2 artificial pneumoperitoneum was established, and five ports were usually used. A 30-degree camera (Karl Storz Endoscopy, Tuttlingen, GER) was used first to inspect the peritoneal cavity to

Table 1

Deviation-based cost modelling analysis: defining deviations from the expected hospital course.

Deviation	Hospital course[a]	Clinical impact
On-course	LOS ≤ 50th percentile	None or minimal deviation from the expected hospital course: Limited to grade I and II postoperative complications
Minor deviation	LOS 50–75th percentile	None or minimal deviation from the expected hospital course: Limited to grade I and II postoperative complications
Moderate deviation	LOS > 75th percentile	None or minimal deviation from the expected hospital course: Limited to grade I and II postoperative complications
	Any hospital duration	Moderate deviation from the expected hospital course: Grade IIIa postoperative complications
Major deviation	Any hospital duration	Major deviation from the expected hospital course: Grade IIIb, IV, and V postoperative complications

Adapted from Vanounou, *et al.*[22] and Vanounou, *et al.*[29].

LOS, length of stay.

[a]The 50th and 75th percentiles correspond to length of stay within the cohort or practice to be analyzed. The 50th percentile represents the expected (median) hospital course.

rule out any extrahepatic disease. Selective hemihepatic inflow occlusion or intermittent Pringle manoeuvre was used when necessary. After the liver was mobilized, a harmonic scalpel (Ethicon Endo-Surgery) was used to transect the liver parenchyma, in combination with other instruments such as the electrocoagulator, Hem-o-lok clip, and Endo-Linear Cutter (Ethicon Endo-Surgery). Intraoperative cholangioscopic lithotomy was used through the common bile duct or the stump of the left or right hepatic duct, followed by primary suture or placement of a T-tube. If the gallbladder was still present, cholecystectomy was performed. The specimens and stones were placed in a plastic bag, removed through a small incision of 4–6 cm, and examined. The abdominal cavity was thoroughly irrigated, and drainage tubes were placed.

All patients received postoperative monitoring, intravenous fluid infusion, liver protection treatment, and short-term antimicrobial prophylaxis using first-generation or second-generation cephalosporin antibiotics[28]. Patients requiring further respiratory and circulatory support were admitted to the ICU for 1–3 days and then returned to the general ward. The abdominal drainage was removed when the drainage fluid was serous and there was no bile leakage.

Follow-up

Postoperative follow-up began one month after the operation or T-tube cholangiography, followed by check-ups every 3–6 months or whenever the patient was suspected to have a stone recurrence. Ultrasonography was usually carried out. Computed tomography or magnetic resonance imaging was performed when necessary. The final deadline was 30 June 2023.

Deviation-based cost modelling

Overall hospital charges were available for all patients undergoing hepatectomy, which included various expenses for examinations, surgery, anaesthesia, monitoring, medications, nursing care, beds, and air conditioning usage during this hospitalization. No post-discharge care, follow-up, readmission, and nursing home costs were included in this analysis. In order to account for the contribution of the type of surgical approach, complication, and postoperative hospital stay to hospital costs, deviation-based cost modelling (DBCM) was used. DBCM was initially developed to reflect the clinical and financial impact of clinical pathway implementation or pancreaticoduodenectomy[29], and later used by the same authors and others to evaluate the clinical and economic value of specific procedures or technologies[21,22,30,31]. Deviations, in contrast to complications, represent any departure from the expected hospital course. In essence, they more accurately characterize the clinical and economic impact of complications of variable severity. Based on the length of hospital stays and the degree of complications, DBCM classifies the hospital courses of all patients studied into the following four categories: on-course, minor deviation, moderate deviation, and major deviation. Definitions for each deviation class are listed in Table 1[22,29]. The central content of DBCM is the concept of deviations from the expected length of hospital stay for the procedure of interest. It provides more precise information than cost data and complication rates alone, as it incorporates the effects of complications, length of hospital stay, and their impact on costs.

In this study, the data on length of postoperative stay were first divided into percentiles based on the entire study cohorts (laparoscopic and open cases). The final deviation of each patient was then determined according to Table 1[22,29]. Complications were graded according to Clavien–Dindo grade[32], with the most severe complication counting for the deviation class. The median hospital costs for each deviation of laparoscopic and open procedures were then counted. Third, the weighted average median cost (WAMC) for each procedure was calculated by combining the relative frequency of each deviation with its median cost as follows (where P indicates the proportion of deviation and C indicates the median cost of deviation)[22,29]: $WAMC = (P_{on\text{-}course} \times C_{on\text{-}course}) + (P_{minor} \times C_{minor}) + (P_{moderate} \times C_{moderate}) + (P_{major} \times C_{major})$. Finally, the financial comparison was performed based on the WAMC of each procedure to determine their relative cost-effectiveness. The difference in WAMCs between OH and LH was the most important index for cost evaluation.

End points

Intraoperative outcomes were hepatic blood flow occlusion, operation duration, estimated blood loss, blood transfusion, and conversion to OH. Short-term outcomes included postoperative ICU stay, pre-discharge complication, length of postoperative hospital stay, 90-day complication, 90-day major complication, re-intervention for complication, initial stone clearance, retreatment for residual stones, final stone clearance, readmission, 90-day mortality, overall hospital charges, WAMC, and difference in WAMCs. Long-term outcomes were stone recurrence, late complication, secondary ICC, and late death.

Outcome definitions

For ease of exposition, we divided all liver resection procedures into three types: left lateral sectionectomy, left hemihepatectomy, and complex hepatectomy. The latter included right posterior sectionectomy, right hemihepatectomy, left lateral sectionectomy combined with right posterior sectionectomy, and any other hepatectomy with caudal lobe resection. Early complications were limited to events that occurred before discharge or within 90 days after surgery. Short-term re-interventions included surgical, endoscopic, or radiological treatments within 90 days after resection because of complications. Readmission was defined as a second hospitalization within 3 months after surgery due to complications or residual stone. Residual stones were defined as the presence of stones in the intrahepatic or extrahepatic bile duct detected by postoperative T-tube cholangiography, ultrasonography, or MRCP within 3 months after hepatectomy[33]. Re-treatment for residual stones included subsequent choledochoscopy or ERCP. Stone recurrence was defined as the recurrence of intrahepatic or extrahepatic stones after the previous stones had been removed. Late complications were limited to new-onset or uncontrolled events that occurred more than 3 months after hepatectomy. Late death was defined as death from late complications or secondary ICC.

Statistical analysis

Normality of continuous variables was assessed by the Kolmogorov–Smirnov test. Normally distributed continuous variables were expressed as mean [SD] and non-normally distributed variables as median [interquartile ranges (IQR)]. Categorical variables were reported as absolute number (percentage). Before statistical analysis, missing data were imputed with a regularized expectation maximization (EM) algorithm. In order to restrict our analysis to the most optimally balanced patient groups, a 1:1 PSM was performed according to the following variables with a caliper of 0.25 (optimal matching)[34]: age, sex, BMI, American Society of Anesthesiologists (ASA) score, previous biliary surgery, obstructive jaundice, concomitant benign liver lesions, type of hepatectomy procedures, biliary exploration, and year of resection. Baseline balances within the selected and unselected cohorts were assessed with standardized mean difference (SMD). An SMD of less than 10% represented a negligible demographic difference[35].

Clinical outcomes in the matched cohorts were analyzed with conditional logistic regression, and conditional odds ratio (cOR) with a 95% confidence interval was calculated. For outcomes with fewer than 5 observations, the McNemar test was performed. Matched hospital costs were analyzed with the Wilcoxon test due to non-normally distributed continuous variables. Outcomes in the unmatched cohorts were appraised with the *t*-test, Mann–Whitney test, and χ^2 test or Fisher's exact test, respectively. Univariate and multivariate analyses were utilized to evaluate the influencing factors of postoperative 90-day overall complications and total hospital costs. A two-sided P less than 0.05 was considered to be statistically significant. Analyses were performed with R software, version R4.2.2.2 (Matching and CreateTableOne packages, R Foundation for Statistical Computing) and IBM SPSS statistics, version 25.0 (IBM Corporation).

Results

Baseline characteristics

A total of 853 hospitalized patients with hepatolithiasis were retrieved. Of these, 790 patients suffered from primary hepatolithiasis. After exclusions, 403 patients undergoing anatomical liver resection were systematically studied: 143 undergoing OH and 260 LH (Fig. 1). There were no missing preoperative data except for BMI (145 [36.0%]). Data imputation resulted in the completion of these variables. There were significant differences in multiple covariates between the unmatched patients (SMD > 10%). PSM resulted in 100 patients undergoing OH (mOH) and 100 LH (mLH) (Table 2). After matching, a comparison of matched patients undergoing OH and LH resulted in an SMD less than 10% for all baseline characteristics. Furthermore, both comorbidities and previous surgical procedures were balanced between the two groups (Supplementary Table 1, Supplemental Digital Content 1, http://links.lww.com/JS9/B704, 2, Supplemental Digital Content 2, http://links.lww.com/JS9/B705), and the proportion of surgical procedures of complex hepatectomy was also balanced (Supplementary Table 3, Supplemental Digital Content 3, http://links.lww.com/JS9/B706). Non-matching patients were discarded.

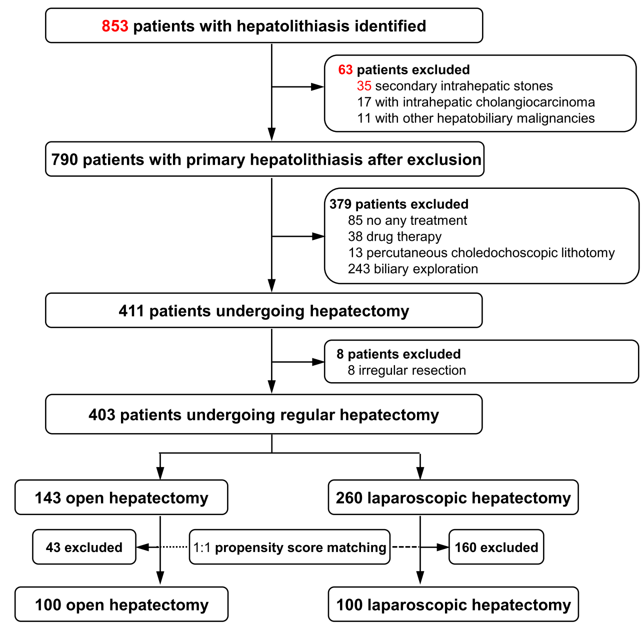

Figure 1. Flowchart depicting the number of patients included in study analyses.

Clinical outcomes

The median operation duration in the mLH group was significantly longer than that in the mOH group (median 285.0 versus 240.0 min, respectively, $P < 0.001$) (Table 3). No significant differences were observed in hepatic blood flow occlusion, blood loss, and blood transfusion rate. Twelve cases (12.0%) in the mLH group were converted to open surgery due to difficulties in dissection or stone removal. Compared with the mOH group, mLH patients required a shorter median postoperative hospital stay (median 8 versus 12 days, respectively, $P < 0.001$). Both predischarge (26% versus 43%, respectively, $P = 0.009$) and 90-day overall complication (33 versus 48%, respectively, $P = 0.025$) rates of the mLH group were significantly lower than those of the mOH group. In addition, the wound ($P = 0.004$) and abdominal infection ($P = 0.021$) rates of the mLH groups were also lower

Table 2

Baseline characteristics.

Characteristic	Before propensity score matching			After propensity score matching		
	OH (*N* = 143)	LH (*N* = 260)	SMD	mOH (*N* = 100)	mLH (*N* = 100)	SMD
Male, *n* (%)	43 (30.1)	97 (37.3)	15.4%	36 (36.0)	37 (37.0)	2.1%
Age, median (IQR), years	62.0 (51.0–66.0)	59.0 (51.0–67.8)	6.2%	61.5 (50.0–66.0)	60.0 (52.0–67.8)	5.5%
BMI, median (IQR), kg/m^2	20.8 (18.7–22.5)	21.9 (20.3–23.9)	39.7%	21.1 (19.5–23.6)	21.4 (19.4–24.2)	3.7%
ASA score 2–3, *n* (%)	65 (45.5)	110 (42.3)	6.0%	40 (40.0)	44 (44.0)	8.0%
Prior biliary surgery, *n* (%)	84 (58.7)	111 (42.7)	33.3%	49 (49.0)	48 (48.0)	2.0%
Obstructive jaundice, *n* (%)	26 (18.2)	55 (21.2)	7.5%	20 (20.0)	22 (19.6)	4.9%
Liver lesions, *n* (%)	125 (87.4)	214 (82.3)	14.3%	88 (88.0)	88 (88.0)	0.0%
Type of hepatectomy, *n* (%)			31.5%			4.3%
Left lateral sectionectomy	66 (46.2)	110 (42.3)		44 (44.0)	42 (42.0)	
Left hemihepatectomy	52 (36.4)	127 (48.8)		41 (41.0)	43 (43.0)	
Complex hepatectomy[a]	25 (17.5)	23 (8.8)		15 (15.0)	15 (15.0)	
Biliary exploration, *n* (%)	143 (100.0)	227 (87.3)	53.9%	100 (100.0)	100 (100.0)	0.0%
Operation during 2019–2022, *n* (%)	49 (34.3)	182 (70.0)	76.6%	43 (43.0)	54 (43.0)	0.0%

ASA, American Society of Anesthesiologists; IQR, interquartile range; LH, laparoscopic hepatectomy; mLH, matched laparoscopic hepatectomy; mOH, matched open hepatectomy; OH, open hepatectomy; SMD, standardized mean difference.

[a]Complex hepatectomy includes right posterior sectionectomy, right hemihepatectomy, left lateral sectionectomy combined with right posterior sectionectomy, and all other hepatectomy.

than those of the mOH group (Supplementary Table 4, Supplemental Digital Content 4, http://links.lww.com/JS9/B707). According to the presence or absence of 90-day overall complications, univariate and multivariate analyses showed that laparoscopic procedure was an influential factor for 90-day complications (Supplementary Table 5, Supplemental Digital Content 5, http://links.lww.com/JS9/B708). No differences were found between the two groups in terms of postoperative ICU stays, major complications, subsequent re-interventions, and readmission rates (Table 3). No patient in the mOH group died during the operation or within postoperative 90 days, while one in the mLH group died of uraemia-related pulmonary infection on the 10th day after surgery.

Three patients in the mOH group and six in the mLH group had no postoperative imaging data, so they were excluded when the initial stone clearance rates were calculated. The initial stone clearance rates were 79.4% (77/97) for the mOH group and 84.0% (79/94) for the mLH group ($P = 0.405$) (Table 3). No

Table 3

Clinical outcomes of propensity score-matched samplesa[a].

Outcomes	mOH (*N* = 100)	mLH (*N* = 100)	cOR (95% CI)/χ^2/Z	*P*
Selective hepatic blood flow occlusion	48/100 (48.0)	48/100 (48.0)	1.000 (0.568–1.761)	1.000
Operation duration, median (IQR), min	240.0 (180.0–290.0)	285.0 (213.5–360.0)	1.009 (1.005–1.013)	< 0.001
Blood loss, median (IQR), ml	200.0 (81.3–375.0)	188.1 (75.0–330.7)	1.000 (0.999–1.001)	0.967
Blood transfusion, *n* (%)	29/100 (29.0)	20/100 (20.0)	0.640 (0.342–1.199)	0.163
Conversion to OH, *n* (%)	—	12 (12.0)	—	—
Postoperative ICU stay, *n* (%)	9/100 (9.0)	16/100 (16.0)	2.000 (0.807–4.955)	0.134
Postoperative stay, median (IQR), days	12.0 (9.0–15.8)	8.0 (7.0–11.0)	0.877 (0.817–0.942)	< 0.001
Pre-discharge complications, *n* (%)	43/100 (43.0)	26/100 (26.0)	0.393 (0.196–0.789)	0.009
Pre-discharge major complications, *n* (%)	3/100 (3.0)	3/100 (3.0)	NA[b]	1.000
90-day complications, *n* (%)	48/100 (48.0)	33/100 (33.0)	0.483 (0.255–0.914)	0.025
90-day major complications, *n* (%)	4/100 (4.0)	6/100 6.0)	NA[b]	0.727
Re-interventions within 90 days, *n* (%)	4/100 (4.0)	6/100 6.0)	NA[b]	0.727
Readmission within 90 days, *n* (%)	18/100 (18.0)	17/100 (17.0)	0.941 (0.476–1.863)	0.862
90-day mortality, *n* (%)	0/100 (0.0)	1/100 (1.0)	—	—
Initial stone clearance rate[c]	77/97 (79.4)	79/94 (84.0)	0.693	0.405
Re-treatment for residual stones[c]	12/97 (12.4)	9/94 (9.6)	0.382	0.537
Final stone clearance rate[c]	83/97 (85.6)	83/94 (88.3)	0.313	0.576
Follow-up, median (IQR), mo[d]	40.5 (23.0–61.5)	45.0 (18.0–62.0)	10.502	0.616
Stone recurrence[e]	14/83 (16.9)	9/82 (11.0)	1.194	0.275
Late complications[d]	4/97 (4.1)	4/93 (4.3)	—	1.000
Secondary ICC[d]	0/97 (0.0)	0/93 (0.0)	—	—
Late death due to complications or ICC[d]	1/97 (1.0)	0/93 (0.0)	—	1.000

cOR, conditional odds ratio; ICC, intrahepatic cholangiocarcinoma; IQR, interquartile range; mLH, matched laparoscopic hepatectomy; mOH, matched open hepatectomy; NA, not applicable.

[a]Data are presented as number/total number (percentage) of patients unless otherwise indicated.

[b]McNemar test instead of conditional logistic regression because of fewer than 5 observations in one group; therefore, no cOR and 95% CI were reported.

[c]Three patients in the mOH group and 6 in the mLH group had no postoperative imaging data, so they were excluded. χ^2 test was used.

[d]Three patients in the mOH group and 7 in the mLH group were excluded because of no postoperative imaging data or early death, Mann–Whitney U test or Fisher's exact test was used.

[e]Seventeen patients in the mOH group and 18 in the mLH group were further excluded because of no follow-up data, residual stones or early death, χ^2 test was used.

differences were observed in subsequent re-treatment, final stone clearance, median follow-up length, stone recurrence, late complication (Supplementary Table 6, Supplemental Digital Content 6, http://links.lww.com/JS9/B709), secondary ICC, and late death between the two groups (Table 3).

DBCM and economic outcomes

Median overall hospital cost of the mLH group was significantly higher than mOH (median CNY¥52,196.1 versus 45,349.5, respectively, $P=0.007$) with an increase of CNY¥6,846.6 per patient undergoing LH (Table 4). After all hospital costs of the 200 matched patients were divided into two groups by a median of CNY¥49,818.9, univariate and multivariate analyses showed that laparoscopic procedure, year of operation, operation duration, and postoperative hospital stay were the influential factors of hospital costs (Supplementary Table 7, Supplemental Digital Content 7, http://links.lww.com/JS9/B710). DBCM revealed that there were significant differences in deviation mix between the two groups ($P<0.001$) (Table 4). More patients undergoing LH have an on-course hospitalization than their OH counterparts (72.0% versus 40.0%, respectively). Compared with the mOH group, the median hospital costs of the mLH group had significant increases across all deviations except for major deviation ($P=0.001$, 0.001, and 0.041, respectively). The WAMC for mLH patients was CNY¥54,246.6 compared with CNY¥44,491.4 for mOH patients, with an average increase of CNY¥9,755.2, which was higher than the increase (CNY¥6,846.6) per person calculated with median overall hospital costs.

Discussion

This propensity score-matched study compared the clinical and economic outcomes of LH with OH for primary hepatolithiasis. Of 403 patients undergoing anatomical hepatectomy for primary hepatolithiasis, PSM resulted in 100 patients in each group and a baseline balance between the matched two groups. We found that LH significantly reduced postoperative hospital stays and complications for patients with primary hepatolithiasis compared with OH, although LH required a longer operation duration. No differences were found in blood loss, major complications, stone clearance, stone recurrence, and mortality between the two groups. However, LH required higher hospital costs and WAMC. To our knowledge, this is the first large sample clinical trial that comprehensively compares the clinical and economic outcomes of laparoscopic versus open liver resection for primary hepatolithiasis using PSM, DBCM, and WAMC.

Some studies suggest LH can shorten the operation duration and reduce blood loss in patients with hepatolithiasis[7,13,16,18]. However, we found that LH required a longer operation duration than OH in this study, with similar blood loss and blood transfusion rates. Our results were the same as the reports of Tian *et al.*[27], and different from other studies[7,13,16,18]. Patients with hepatolithiasis usually have multiple stones, abnormal structures, and dense perihepatic adhesions caused by chronic recurrent inflammation and previous biliary surgery[11,14]. This makes performing LH more challenging than OH for hepatolithiasis. Tian *et al.*[27] also think it is more difficult to perform LH for hepatolithiasis than for tumours. In this study, all patients in the mLH

Table 4

Deviation-based cost modelling analysis: comparing economic outcomes for matched laparoscopic versus open hepatectomy.

	mOH (*N*=100)	mLH (*N*=100)	Z/χ^2 Value	*P*
Overall hospital costs, median (IQR), CNY¥	45, 349.5 (35, 172.7–57, 334.6)	52, 196.1 (45, 605.2–61, 720.6)	– 2.706[a]	0.007
Cost increasing per patient, CNY¥		6, 846.6	—	—
Percentile of postoperative stay, *n* (%)			24.652[b]	< 0.001
≤ 50th percentile (≤ 10 days)	40 (40.0)	74 (74.0)	—	—
50–75th percentile (11–14 days)	29 (29.0)	16 (16.0)	—	—
> 75th percentile (>15 days)	31 (31.0)	10 (10.0)	—	—
Pre-discharge complications, *n* (%)			NA[c]	0.043
None	57 (57.0)	74 (74.0)	—	—
grade I	25 (25.0)	17 (17.0)	—	—
Grade II	15 (15.0)	6 (6.0)	—	—
Grade IIIa,	3 (3.0)	2 (2.0)	—	—
Grade IIIb, IV, V	0 (0.0)	1 (1.0)	—	—
Deviation mix, *n* (%)			NA[c]	< 0.001
On-course[a]	40 (40.0)	72 (72.0)	—	—
Minor deviation	29 (29.0)	16 (16.0)	—	—
Moderate deviation	31 (31.0)	11 (11.0)	—	—
Major deviation	0 (0.0)	1 (1.0)	—	—
Median hospital costs, CNY¥				
On-course	38, 239.3	49, 789.1	– 3.352[d]	0.001
Minor deviation	42, 518.1	58, 064.7	– 3.462[d]	0.001
Moderate deviation	54, 404.7	73, 073.4	– 2.045[d]	0.041
Major deviation	—	107, 003.7	—	—
Weighted average median hospital costs, CNY¥	44, 491.4	54, 246.6	—	—
Overall cost increasing per patient, CNY¥		9, 755.2	—	—

CNY, Chinese Yuan; IQR, interquartile range; mLH, matched laparoscopic hepatectomy; mOH, matched open hepatectomy; NA, not applicable.
[a]Wilcoxon test was used for matched data.
[b]χ^2 test was used.
[c]No χ^2 were reported for Fisher's exact test.
[d]Mann–Whitney U test was used.

group underwent total laparoscopic resection with 48% having a history of biliary surgery, and involved relatively complex hepatectomy or major hepatectomy, which was known to affect the difficulty of operation. We found that laparoscopic liver dissociation, transection of liver parenchyma, and stone removal were very time-consuming, resulting in prolonged operative time and increased blood leakage. As results, LH prolonged the operation duration without reducing total blood loss and blood transfusion. Nonetheless, as non-extremely prolonged operation duration and unreduced blood loss are generally acceptable, LH still has similar safety and feasibility as OH for hepatolithiasis.

Some authors reported that LH can reduce the occurrence of postoperative complications[15,18]. Our study showed that LH mainly reduced incision infections, leading to lower pre-discharge and 90-day overall complication rates. However, LH did not reduce the major complication, subsequent re-intervention, and readmission. The occurrence of major complications is mainly determined by the severity of the lesion, surgical procedures, and intraoperative manipulation. Therefore, LH is unlikely to decrease or increase the major complication rate. More importantly, we found that LH can significantly shorten postoperative hospital stays. Our conclusion of postoperative hospital stay was in line with most studies[7–19,27]. This may have been due to the roles of small incision, mild pain, and mild postoperative inflammatory response. These results demonstrate the advantages of minimal invasion and fast recovery of the laparoscopic approach. In addition, our research found there were no differences in initial stone clearance, final clearance, stone recurrence, late complication, and mortality between the two groups. In short, the efficacy of LH is superior or equal to OH for primary hepatolithiasis.

If LH is clinically and economically equivalent or superior to OH for hepatolithiasis, this could lead to greater acceptance of LH by liver surgeons, patients, and health managers. Some studies on laparoscopic liver resection for liver tumours suggest that fewer postoperative complications and shorter hospital stays may reduce or, at least, not increase the overall hospital costs or WAMC of LH[20–25]. In investigate the economic value of LH in hepatolithiasis, we first compared the overall hospital costs of the two groups and found for the first time that the median overall hospital cost of the mLH group was significantly higher than that of the OH group. Multivariate analyses showed that the laparoscopic procedure, operation duration, and postoperative hospital stay, rather than the pre-discharge complication, were the influencing factors of overall hospital costs. The economic impact of clinical differences was then evaluated from the DBCM perspective. Surprisingly, the WAMC was also higher for the mLH group than for the mOH group, although the mLH patients had fewer pre-discharge complications and shorter postoperative hospital stays, which is completely different from previous research on liver tumours[20–25]. The advantage of DBCM is that it incorporates the impact of complications and hospital stays on costs, thus providing more precise information than cost data and complications alone. In our study, although there were significant differences in deviation mix, with more LH patients having an on-course hospitalization than their OH counterparts, the median hospital costs of most deviations were significantly higher in the mLH group than in the mOH group resulting in higher WAMC.

Laparoscopic surgery for hepatolithiasis at our institution required a large amount of high-end medical consumables, including endolinear cutters, haemostatic clips, haemostatic gauze, a disposable cutter head of ultrasonic knife, and electrode wires of lithotripter. These medical consumables significantly increased intraoperative costs. In addition, longer operation duration also increased anaesthesia and monitoring costs. This was confirmed by some studies on LH for liver tumours[21,24,25]. Therefore, early discharge and few complications of LH patients were far from sufficient to offset the increase in intraoperative costs, because the hospital charges at our hospital were mainly incurred in the operating room and in the first few days after surgery, with few costs in the late phase of hospitalization. Although the costs of different departments (such as ward, operating room, pharmacy, imaging centre, and ICU) were not calculated due to lack of cost statistics by department, our study suggests that the cost increase in LH patients may be primarily associated with significantly higher intraoperative costs, despite the significantly shorter postoperative hospital stays and fewer complications. Therefore, efforts to reduce operative costs of LH, while maintaining optimal clinical outcomes, should be the focus of surgeons and hospitals moving forward.

Of course, this trial has several limitations. Despite collecting extensive data, some information was still lacking due to the retrospective study design, such as the surgeon's reasons for OH or LH and the location of stones. EM imputation had to be performed for BMI in 36.0% of the 403 patients, which might cause bias. However, differences between the two selected groups can be ignored because all SMDs were less than 10% after matching. Additionally, all laparoscopic procedures were combined as a whole and compared with the OH group in this study. Therefore, it is currently unclear whether all types of LH comply with the conclusion.

Conclusion

The overall clinical benefit of LH for hepatolithiasis is comparable or even superior to that of OH, but with an economic disadvantage. There is a need to effectively reduce the hospital costs, especially operative charges, of LH and the gap between costs and DRG reimbursement to promote the use of LH in the treatment of hepatolithiasis. Further research is needed to investigate the clinical and economic value of different types of laparoscopic procedures.

Ethical approval

This study was approved by the institutional review board of Yijishan Hospital of Wannan Medical College (Grant No. [2022] 106), China.

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Author contribution

X.-P.C.: conceptualization, data curation, formal analysis, investigation, project administration, and writing—original draft. W.-J.Z.: data curation, formal analysis, investigation, project administration, and writing—original draft. B.C.: formal analysis, methodology, software, validation, and writing—original draft. Y.-L.Y.: investigation, project administration, and validation. J.-L.P.: investigation, project administration, and validation. S.-H.B.: investigation, project administration, and supervision. C.-G.T.: software, validation, and writing—review and editing. J.Z.: conceptualization, supervision, writing—review and editing.

Conflicts of interest disclosure

Not applicable.

Research registration unique identifying number (UIN)

1. Name of the registry: Key techniques, surgical procedures and treatment system of laparoscopic hepatectomy for hepatolithiasis.
2. Unique Identifying number or registration ID:Chinese Clinical Trial Registry: ChiCTR2300072545.
3. Hyperlink to your specific registration (must be publicly accessible and will be checked): Chinese Clinical Trial Registry: www.chictr.org.cn.

Guarantor

Xiao-Peng Chen is the Guarantor. All authors read and approved the final manuscript.

Data statement

The authors state that their research date will be made available from the corresponding author on reasonable request.

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