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ORIGINAL ARTICLE

Laparoscopic versus open hemihepatectomy—a cost analysis after propensity score matching

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Abstract

Introduction Cost efficiency is important for hospitals in order to provide high-quality health care for all patients. As hemihepatectomies are increasingly being performed laparoscopically, the aims of this study were to evaluate the costs of laparoscopic hemihepatectomy and to compare them to conventional open techniques.

Patients and methods This is a retrospective analysis of clinical outcomes and financial calculations of all patients who underwent hemihepatectomy between January 2015 and December 2016 at the Department of Surgery, Campus Charité Mitte and Campus Charité Virchow-Klinikum, Berlin, Germany, being allocated to the DRG (diagnosis-related group) H01A (complex operations of the liver and pancreas with complex intensive care treatment) or H01B (operations of the liver and pancreas without complex intensive care treatment). To overcome selection bias, a 1:1 propensity score matching (PSM) analysis was performed.

Results After PSM, a total of 64 patients were identified; 32 patients underwent laparoscopic hemihepatectomy (LH); and 32 patients received open hemihepatectomy (OH). After PSM, no significant differences were observed in clinical baseline characteristics. The duration of surgery was significantly longer for patients undergoing LH compared to OH (LH, 334 min, 186–655 min; OH, 274 min, 176–454 min; $p = 0.005$). Patients in the LH group had a significantly shortened median hospital stay of 5 d, when compared to OH (LH, 9.5 d, 3–35 d; OH, 14.5 d, 7–37d; $p = 0.005$). We observed a significant higher rate of postoperative complication in the OH group ($p = 0.022$). Cost analysis showed median overall costs of 17,369.85€ in the LH group and 16,103.64€ in the OH group ($p = 0.390$).

Conclusion Our data suggest that higher intraoperative costs of laparoscopic liver surgery, e.g., for surgical devices and due to longer operation times, are compensated by fewer postoperative complications and consecutive shorter length of stay when compared with OH.

Keywords Hemihepatectomy · Laparoscopy · Cost analysis

Introduction

Many studies have established laparoscopy as the default procedure to treat a broad panoply of diseases comprising various surgical fields [1, 2]. The rationale behind the success of laparoscopy is the reduction of the operative trauma, eliciting shorter hospital stay, and lower morbidity while maintaining high-quality oncologic outcomes [3, 4]. The potential transfer of these beneficial aspects to liver surgery has initially been met with skepticism as evidence for benefits was perceived as insufficient [3, 5]. While in the beginnings, only left lateral sectionectomy, the technically most feasible anatomical resection, was considered to be the standard practice, nowadays both left and right hepatectomy, as well as complex anatomical resections, and living donor hepatectomy are routinely performed laparoscopically by experienced centers worldwide [6]. Multiple retrospective studies have shown both comparable perioperative as well as oncologic outcomes for laparoscopic and open techniques [7, 8].

The experience of our center mirrors the worldwide experience of high volume HBP centers with regard to the development of laparoscopic liver resection (LLR). The rate of laparoscopic procedures has increased markedly in recent years. However, beside positive clinical outcomes of the laparoscopic approach, the cost factor for hospitals providing

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laparoscopic liver surgery has to be considered. Due to a longer operation time and the use of expensive laparoscopic instruments and consumables, these procedures are said to increase costs for the medical health-care system. While others have reported a cost advantage of laparoscopic liver surgery, most of these studies have included a small number of patients with minor liver resections [9, 10]. A recently published study showed a cost efficiency of laparoscopic compared to open hemihepatectomys in an unmatched patients cohort [11].

The aim of this study was to compare the costs of laparoscopic and open hemihepatectomy to analyze expenses of complex laparoscopic liver surgery and thus help to establish a higher planning reliability for hospitals aiming to introduce minimal-invasive techniques.

Patients and methods

This is a single-center retrospective analysis of the costs of laparoscopic versus open hemihepatectomy in a consecutive cohort of patients. Patients were operated between January 2015 and December 2016 at the Department of Surgery, Campus Charité Mitte and Campus Charité Virchow-Klinikum, Berlin, Germany. Institutional review board approval (application no. EA2/006/16) was obtained before analysis of the data. In order to evaluate the costs of hospitals providing complex laparoscopic liver surgery, only patients in the DRG (diagnosis-related group) H01A (complex operations of the liver and pancreas with complex intensive care treatment) and H01B (operations of the liver and pancreas without complex intensive care treatment) were included. For better comparability, patients being appointed to a different DRG due to long-term stay on an intensive care unit because of respiratory or multiorgan failure and conversions were excluded (Fig. 1).

To overcome selection bias, a propensity score matching was performed based on preoperative characteristics including sex, age at time of surgery, body mass index (BMI), American Society of Anaesthesiologists (ASA) score, steatosis and fibrosis grade, cirrhosis, malignant disease, intrahepatic cholangiocarcinoma (iCC), previous abdominal surgery, and right hemihepatectomy. Routinely preoperatively performed diagnostics included blood tests and computed tomography (CT) of the chest and abdomen as well as magnetic resonance imaging (MRI), as indicated.

Operation techniques At our center, different approaches are available for laparoscopic hemihepatectomy depending on size and localization of the hepatic lesion as well as the pathologic entity. The multiport laparoscopic liver resection (MILL) is performed via a 12-mm trocar placed in the umbilical region with additional 12-mm and 5-mm trocars, as

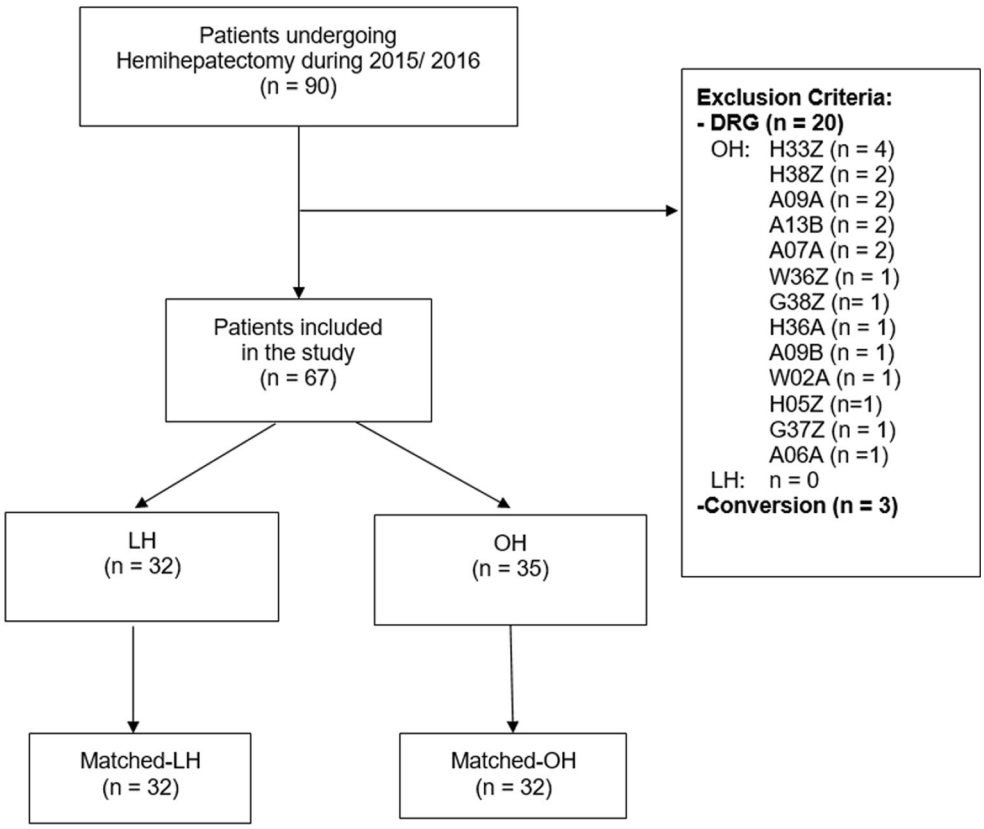

Fig. 1 PRISMA 2009 flow chart for exclusion criteria

Table 1 Preoperative patient characteristics in LH and OH groups before and after PSM

	LH ($n = 32$)	OH ($n = 35$)	p value	Matched-LH ($n = 32$)	Matched-OH ($n = 32$)	p value
Age (years)	59.5 (19–82)	63 (21–81)	0.720[†]	59.5 (19–82)	62 (21–81)	0.495[§]
Female, n (%)	19 (59.4)	17 (48.6)	0.376[ß]	19 (59.4)	16 (50.0)	0.549[$]
ASA 1 and 2, n (%)	21 (65.6)	22 (62.9)	0.907[ß]	21 (65.6)	20 (62.5)	1.0[$]
ASA 3 and 4, n (%)	11 (34.4)	13 (37.1)		11 (34.4)	12 (37.5)	
BMI (kg/m^2)	24.0 (16.6–39.7)	25.6 (18.3–37.6)	0.327[†]	24.0 (16.6–39.7)	24.35 (18.3–34.1)	0.449[§]
Steatosis grade	0 (0–70)	0 (0–80)	0.899[†]	0 (0–70)	0 (0–80)	0.653[§]
Fibrosis grade	1 (0–4)	0 (0–4)	0.369[†]	1 (0–4)	0.5 (0–4)	0.199[§]
Cirrhosis, n (%)	5 (15.6)	2 (5.7)	0.246[†]	5 (15.6)	2 (6.3)	0.453[§]
Preoperative Chemotherapy	11 (34.4)	7 (20.0)	0.185 [ß]	11 (34.4)	7 (21.9)	0.454[§]
Malignant, n (%)	21 (65.6)	26 (74.3)	0.439[ß]	21 (65.6)	23 (71.9)	0.754[$]
iCC, n (%)	3 (9.4)	10 (28.6)	0.047[ß]	3 (9.4)	7 (21.9)	0.125[$]
Underlying disease						
HCC, n (%)	6 (18.8)	8 (22.9)		6 (18.8)	8 (25.0)	
CRLM, n (%)	10 (31.3)	7 (20)		10 (31.3)	7 (21.9)	
iCC, n (%)	3 (9.4)	10 (28.6)		3 (9.4)	7 (21.9)	
Other malign, n (%)	2 (6.3)	1 (2.9)		2 (6.3)	1 (3.1)	
Adenoma, n (%)	1 (3.1)	1 (2.9)		1 (3.1)	1 (3.1)	
FNH, n (%)	2 (6.3)	1 (2.9)		2 (6.3)	1 (3.1)	
Hemangioma, n (%)	1 (3.1)	1 (2.9)		1 (3.1)	1 (3.1)	
Caroli-Syndrome, n (%)	2 (6.3)	1 (2.9)		2 (6.3)	1 (3.1)	
Echinococcosis, n (%)	3 (9.4)	2 (5.7)		3 (9.4)	2 (6.3)	
Other benign, n (%)	2 (6.3)	3 (8.6)		2 (6.3)	3 (9.4)	
Previous abdominal surgery, n (%)	13 (40.6)	17 (48.6)	0.514[ß]	13 (40.6)	15 (46.9)	0.824[$]
Right HH, n (%)	20 (62.5)	22 (62.9)	0.976[ß]	20 (62.5)	22 (68.8)	0.791[$]

LH, laparoscopic hemihepatectomy; OH, open hemihepatectomy; BMI, body mass index; ASA, American Society of Anaesthesiologists score; HCC, hepatocellular carcinoma; CRLM, colorectal liver metastases; iCC, intrahepatic cholangiocarcinoma; FNH, focal nodular hyperplasia

[ß] Chi-square test

[†] The Mann-Whitney U test

[§] The Wilcoxon singed-rank test

[$] The McNemar test

needed. The specimen is usually being removed via a suprapubic or umbilical incision. The hand-assisted laparoscopy (HALS) is performed via a handport placed through an epigastric midline incision and further 12-mm and 5-mm trocars can be placed as indicated. The resected part of the liver is being removed through the handport incision.

In both approaches, the senior surgeon stands between the legs of the patient who is in supine position. The assistant surgeon stands at the left side of the patient. The pneumoperitoneum is maintained by an intra-peritoneal pressure of 10–14 mmHg, as needed. Laparoscopic ultrasound is being routinely used to locate the intrahepatic lesions.

Various options for parenchymal dissection exist for both approaches. At our center, Thunderbeat® (Olympus K.K., Tokyo, Japan) and Harmonic Ace® (Ethicon Inc. Somerville, NJ, USA) are commonly used for superficial transection. Laparoscopic ultrasonic surgical aspirator (CUSA) and Waterjet (Erbe, Tübingen, Germany) are favored for deeper parenchymal transection. Vascular staplers (Echelon, Ethicon, Somerville, New Jersey, USA) are also available for dissection of both larger vessels and bile ducts as well as parenchyma.

Open hemihepatectomy is performed via a midline incision with rightward extension. A CUSA is routinely used for parenchymal dissection with transection of crossing vessel between titanium clips or sutures.

Clinical data collection We collected the following data: indication for surgery, perioperative transfusions, duration of surgery, length of intensive care stay (ICU), length of hospitalization (LOS), postoperative major complications within 30 days (the Dindo-Clavien > II) and oncological outcome [12]. The resected tissue was examined by pathologists of our center.

Table 2 Perioperative clinical data comparing LH and OH groups after PSM

	Matched-LH ($n = 32$)	Matched-OH ($n = 32$)	p value
Operation time (range min)	334 (186–655)	274 (176–454)	0.005§
ICU stay (range days)	1 (1–6)	1 (1–7)	0.548§
Hospital stay (range days)	9.5 (3–35)	14.5 (7–37)	0.005§
R1 resection	2 (9.5)	2 (8.7)	1.0$
Postoperative complications, the Clavien-Dindo score III–V (%)	5 (15.6)	11 (34.4)	0.210$
Grade I	0 (0)	4 (12.5)	0.022*
Grade II	3 (9.4)	5 (15.6)	
Grade III	3 (9.4)	11 (34.3)	
Grade IV	1 (3.1)	0 (0)	
Grade V	1 (3.1)	0 (0)	

LH, laparoscopic hemihepatectomy; OH, open hemihepatectomy; ICU, intensive care unit

§ The Wilcoxon singed-rank test

$ The McNemar test

* The Friedman test

Financial data collection Cost analysis was performed by using the data collected by the independent controlling department of our center.

Intraoperative costs include costs for operation time per minute, for presence of surgeons per minute, presence of anesthesiologists per minute, laparoscopic devices including staplers and cartridges, equipment for CUSA, and clips. We defined five subgroups of specific laparoscopic devices: stapler, laparoscopic clips, other devices for tissue dissection (e.g., harmonic ace, laparoscopic CUSA), approach, and retrieve devices (e.g., trocars). In addition, we analyzed the postoperative costs including costs for our intensive care units (ICU) and general wards. Perioperative diagnostic and treatment costs include CT, MRI, endoscopic retrograde cholangiopancreatography (ERCP), CT-guided drainage, and perioperative transfusions.

Statistical analysis Categorical variables were expressed as number or frequency (%) and analyzed using chi-squared test. Continuous variables were expressed as median (range), and differences between groups were explored using the Mann-Whitney U test.

To overcome selection bias, a propensity score matching (PSM) was performed based on preoperative characteristics including sex, age at time of surgery, body mass index (BMI), American Society of Anaesthesiologists (ASA) score, steatosis and fibrosis grade, cirrhosis, malignant disease, intrahepatic cholangiocarcinoma (iCC), previous abdominal surgery, and right hemihepatectomy. Descriptive statistics were displayed before and after matching respectively. For PSM a one-to-one nearest neighbor matching analysis without replacement was conducted. After PSM, categorical variables were analyzed using the McNemar test and continuous variables using the Wilcoxon singed-rank test. For analyzing differences between ordinal complication rates between the matched groups, the Friedman test was conducted. Statistical analyses were carried out using the IBM SPSS Statistics 23 and MatchIt package in the software R. Statistical significance was set at $p < 0.050$.

Table 3 Specific costs for laparoscopy

Specific laparoscopic costs for laparoscopy		
	Total costs ($n = 32$)	Median costs per case
Laparoscopic stapler	51,193€	1600€
Laparoscopic clips	4672€	146€
Devices for tissue dissection	10,562€	330€
Approach and retrieve devices	11,578€	362€
Overall	78,005€	2438€

Table 4 Intra-, perioperative, and total costs comparing LH and OH groups after PSM

	Matched LH ($n = 32$) Mean € Median € (range)	Matched OH ($n = 32$) Mean € Median € (range)	p value
Intraoperative costs			
Overall costs surgery	7679.84 8031.5 (4290–11,023)	4224.78 4095 (2554–7555)	<0.001§
Consumables (including laparoscopic specific devices, Table 3)	3338.94 3474.5 (1360–5721)	851.88 743 (339–2425)	<0.001§
Surgical staff	3045.22 2823.5 (1378–5146)	2302.72 2227 (1376–3428)	0.002§
Costs for anesthesia	2210.22 2080.5 (1415–3216)	1999.81 1957.5 (1336–3297)	0.029§
Perioperative costs			
ICU	1385.09 902 (379–5471)	1644.25 878 (505–10,583)	0.955§
General ward	4097.75 3451 (839–13,017)	5999.16 4653.5 (2505–12,934)	0.005§
Transfusion	869.38 891.5 (365–1832)	1061.59 989.5 (466–2098)	0.036§
Radiology (including radiological interventions)	359 236 (21–1754)	446.75 397.5 (21–1673)	0.210§
Endoscopy / Endoscopic interventions	209.13 0 (0–3120)	333.91 0 (0–3308)	0.508§
Other diagnostic features	409.34 410.5 (0–2195)	480.56 469.5 (0–1107)	0.017§
Total costs			
	17,369.85 17,196.22 (9830–30,631)	16,103.64 15,041.77 (8551–24,460)	0.390§

LH, laparoscopic hemihepatectomy; OH, open hemihepatectomy; ICU, intensive care unit

§ The Wilcoxon signed-rank test

Results

Sixty-seven patients met the inclusion criteria during the study period as defined under "Patients and methods." Before PSM, the patient groups did not differ regarding sex, age at time of operation, BMI, ASA score, rate of previous abdominal surgery, rate of right hepatectomy, liver steatosis, fibrosis, and cirrhosis level as well as rate of malignancy. The rate of iCC was significantly higher the OH group ($p = 0.047$, Table 1). After PSM, no significant differences of baseline characteristics between both groups were observed and 32 patients remained in both groups.

The duration of operation was significantly longer for patients undergoing LH compared with OH (LH, 334 min, range 186–655 min; OH, 274 min, range 176–454 min; $p = 0.005$). The median ICU stay was 1 day in both groups and showed no significant difference (LH, 1.3 d, range 1–6 d; OH, 1.7 d, range 1–7 d; $p = 0.548$). However, patients in the LH group had a significantly shorter median hospital stay (LOS) and were discharged 5 d earlier than patients in the OH group (LH, 9.5 d, range 3–35 d; OH, 14.5 d, range 7–37 d; $p = 0.005$, Table 2).

Significantly fewer major complications, as defined as the Dindo-Clavien > II, were observed in patients after laparoscopic surgery, when compared with the open approach ($p = 0.022$). Major complications in the LH group were bile leak ($n = 2$), seroma ($n = 1$), and acute kidney failure ($n = 1$). One patient died due to acute on chronic mesenteric ischemia in the postoperative course, related to pre-existing, massive atherosclerosis. Major complication in the OH group were bile leak ($n = 2$), abscess ($n = 2$), hematoma ($n = 1$), pleural effusion ($n = 1$), cholangitis ($n = 1$), and fluid collection ($n = 1$), which were treated conservatively. In the OH group, three patients needed re-laparotomy due to wound infection ($n = 2$) and bile leak ($n = 1$).

Cost analysis showed median overall costs of 17,196.22€ per patient in the LH group and 15,041.77€ in the OH group ($p = 0.390$). We observed significantly higher intraoperative costs in the LH group (median 8031.5€, range 4290–11,023 €) compared to the OH group (median 4095€, range 2554–

7555€; $p < 0.001$). Costs of specific laparoscopic devices are listed in Table 3. We used a median of 2.4 stapler cartridges in the LH group, which is the highest cost factor apart from operation time. Median cost for ICU stay in the LH group was 902€ (range 379–5471€) and 878€ in the OH group (range 505–10,583€, $p = 0.955$). The median costs for the stay on the general ward were 3451€ in the LH group and significantly lower, when compared to 4653.5€ in the OH group (LH, range 839–13,017€; OH, range 2505–12,934€; $p = 0.005$). When summarizing perioperative costs for CT scans, CT-guided drainage, endoscopy, transfusions, antibiotics, we noted lower costs in the LH (median 1546€, range 391–5781 €) comparing with the OH group (median 2070.50€, range 879–6074€, $p = 0.055$ Table 4).

Discussion

As laparoscopic liver surgery becomes more and more relevant in the treatment of liver tumors and lesions, an adequate cost coverage will be crucial for a wide introduction to hospitals. Due to the high demand of expensive devices and prolonged operation time, intraoperative costs are higher in the minimally invasive approach. However, lower complication and postoperative intervention rates in patients undergoing laparoscopic liver resections have been shown to result in a shorter hospital stay and financial compensation. The potential compensation of higher intraoperative costs of laparoscopic liver surgery has already been described by others [12–14], but to our knowledge none of the studies showed a cost equality exclusively for hemihepatectomies. In these cases, the complexity and duration of the procedure might not be compensable due to the mentioned postoperative benefits.

Our study shows that laparoscopic hemihepatectomies are feasible with a shorter LOS compared to conventional open surgery. Others and we showed a significant longer operation time in the LH group, with a prolongation of nearly 1 h ($p = 0.008$). The complication rate, however, was significantly lower after laparoscopic liver resections, when compared with open surgery ($p = 0.022$).

We analyzed the costs of specific laparoscopic devices and classified five categories. Of the average difference of 3332.9€ of intraoperative cost between LH and OH groups, an average of 2438€ were associated with specific laparoscopic costs. These data show that about 73% of the charges for laparoscopic liver surgery are associated with devices and 26% with the longer operation time. Laparoscopic staplers constitute the largest share of the total expenses. Others have reported a significant reduction of operation time due to the use of laparoscopic staplers [15, 16]. However, in our center, we tend to reduce the number of cartridges to a minimum by using waterjet or ultrasonic dissection, which allows more accurate preparation and isolation of vessels.

We were able to generate profits in both laparoscopic and open groups. Prices for laparoscopic devices are likely to decrease due to expiring patents and operation time can be expected to approximate that of open surgery with growing experience. We therefore predict a reduction of intraoperative costs for laparoscopic liver surgery in the near future. However, due to the retrospective design, one must still make the conclusions carefully. Taken into account that the decision about the laparoscopic vs. open approach was made on an individual basis and surgeon's choice during our learning curve represents a further possible flaw. The aim of this study was to compare the estimated costs of laparoscopic hemihepatectomies vs. conventional open surgery in order to establish a higher planning reliability for hospitals aiming to introduce minimal-invasive techniques to complex liver surgery. That is why we still believe the study has some added values to the current knowledge.

Besides all possible limitations, our study confirms the findings of others that the laparoscopic approach can compensate higher intraoperative charges by a shorter hospital stay and reducing complication-associated costs [17, 18]. We observed a significant difference in complication rates leading to a decrease of perioperative costs for interventions and diagnostic in the LH group. It can be assumed that in laparoscopic hemihepatectomies, the postoperative outcome advantages can reach similarly positive results as in laparoscopic minor resections.

In conclusion, this study shows that laparoscopic hemihepatectomies can be safely performed and that higher intraoperative costs can be compensated by a beneficial postoperative course.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Research involving human participants and informed consent All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Institutional review board approval (application no. EA2/006/16) was obtained before analysis of the data. Approval from the local ethics committee includes the usage and publication of those retrospectively analyzed data. Due to the blinded data and retrospective design, written informed consent was not considered necessary by the ethics committee.

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