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REVIEW ARTICLE

Comparison between robotic and open liver resection: a systematic review and meta-analysis of short-term outcomes

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Abstract

Minimally invasive liver surgery has evolved significantly during the last 2 decades. A growing number of published studies report outcomes from robotic liver resections (RLR). The aim of our meta-analysis was to evaluate short-term outcomes after RLR vs. open liver resection (OLR). A systematic search of Medline, Scopus, Google Scholar, Cochrane CENTRAL Register of Controlled Trials and Clinicaltrials.gov databases for articles published from January 2000 until November 2018 was performed. Ten non-randomized retrospective clinical studies comprising a total of 1248 patients were included in our meta-analysis. Four hundred and fifty-eight patients underwent RLR and 790 underwent OLR. RLRs were associated with lower overall morbidity rates ($p=0.006$) and shorter hospital stay ($p<0.00001$), whereas OLRs were associated with shorter operative time ($p=0.003$). No differences were shown between the two groups with regard to blood loss, blood transfusion requirements, R0 resection and mortality rates. Cumulative conversion rate was 4.6% in the RLR group. Due to limited available data, further prospective randomized studies are needed to better determine the potential beneficial role of the robotic approach in the treatment of malignant and benign hepatic tumors.

Keywords Robotic · Open liver resection · Hepatectomy · Morbidity · Length of stay

Introduction

The introduction and development of minimally invasive approaches during the past decade have revolutionized the field of liver surgery, which was traditionally linked to open liver resection (OLR), often associated with high morbidity rates and prolonged hospitalization [1, 2]. Evolution in the field of laparoscopic liver surgery has established laparoscopic liver resections (LLR) as both safe and feasible for the treatment of primary, metastatic, and recurrent liver lesions [3–9]. Indeed, certified hepatobiliary surgeons proficient in laparoscopic surgery are becoming more daring as more challenging resections are performed indicative of the accumulating experience in reference centers worldwide [9, 10].

Such diffusion of practice leads to a better delineation of the many shortcomings and technical pitfalls related to this approach; the rigidity of the straight laparoscopic instruments that limit accessibility to many liver surface areas, combined with poor ergonomics that tire the surgeon during long procedures, inadvertently lead to increased physiologic tremor that hinders delicate dissection [11]. To that end, the introduction of robotic liver resections (RLR) in the armamentarium of surgeons strives to solve these problems [12, 13]. The cost-related drawbacks of the robotic system constitute a major concern for the wider implementation of this minimally invasive approach, although the existing experience with this method is promising [14–16]. Proponents of the robotic system for liver resections state that superior flexibility and maneuvering of the robotic arms are the keys to allowing more accurate manipulations to perform

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anatomically challenging resections, such as those in the right posterior segments [17–19].

The objective of the present systematic review and meta-analysis was to compare the short-term outcomes of RLR compared to OLR for a plethora of hepatic lesions.

Materials and methods

A systematic search of Medline, Scopus, Google Scholar, Cochrane CENTRAL Register of Controlled Trials and Clinicaltrials.gov databases for articles published from January 2000 until November 2018 was undertaken separately by three authors (DP, IDK and APa), to identify existing literature comparing open to robotic liver resections. The search terms utilized were "robotic", "robot-assisted", "liver resection", "hepatectomy", combined with the boolean operators AND/OR. The abstract list generated by the search was screened by two authors (DP and IDK). All published clinical studies comparing robotic to open hepatectomy were extracted for full-text review. Exclusion criteria were (1) non-clinical studies, case reports, reviews and editorials, (2) non-English studies, (3) studies without available full-text, (4) clinical studies not reporting perioperative outcomes. All articles deemed eligible for inclusion were subsequently reviewed by all authors and were selected for inclusion in the data analysis. This study was conducted according to PRISMA guidelines [20].

Data extraction and management

Data were extracted from eligible studies, inserted in excel spreadsheets (Microsoft, Redmond, Washington, USA) and were reviewed and crosschecked independently by the aforementioned three authors to ensure the absence of any data discrepancies. Data of interest were patient demographics (age, gender, previous abdominal surgery, ASA score, reason for hepatectomy, cirrhosis), lesion characteristics (type, number and size of lesions), type of resection employed (major vs. minor), perioperative and postoperative outcomes.

Quality assessment

The quality of all the included studies was assessed using the Methodological Index for Non-Randomized Studies (MINORS) [21]. This is a quality assessment tool, designed for estimating the methodological adequacy of non-randomized studies. The MINORS scale contains 12 items, each scored from 0 to 2, providing overall scores between 0 and 24. The methodological quality of the included studies was independently assessed by two reviewers (KID and MN). The choice of the MINORS scale was due to the fact that all of the studies included in our meta-analysis were non-randomized.

Statistical analysis

Meta-analysis was performed using Review Manager Version 5.3 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014). Risk ratio (RR) was used for the assessment of dichotomous variables and mean difference was used for the assessment of continuous variables. The inverse variance method was chosen for comparisons between dichotomous or continuous variables. Due to the expected heterogeneity among studies, the random effects model was chosen. Statistical heterogeneity was assessed with the Higgin's I^2 statistic. When mean values and standard deviations were not mentioned in the studies, they were calculated according to the equations proposed by Hozo et al. [22] and 95% confidence intervals (CI) were noted for all results. The level of statistical significance was set at p value less than 0.05.

Results

Included studies

The initial database search yielded 222 results. Following screening of abstracts and exclusion of irrelevant and duplicate studies, 38 full-text articles were reviewed for potential eligibility. Finally, ten non-randomized retrospective clinical studies were included in our meta-analysis, which compared RLR with OLR and were published between 2014 and 2018 (Fig. 1) [18, 23–31]. Three were of European origin [24, 28, 29], three of American origin [25, 26, 30], three of Asian origin [23, 27, 31], and one of mixed origin [18]. The included studies were considered as methodologically adequate according to MINORS scale, with scores ranging from 16 to 22 and an average score of 18.1 [18, 23–31].

Patient characteristics

A total of 1248 patients were included with 458 undergoing RLR and 790 OLR as shown in Table 1 [23–31]. Baseline patient demographics were comparable among the two groups. Specifically, the percentage of male patients was similar in both the RLR and OLR groups [RLR: 266/458 (58.1%), OLR: 490/790 (62%), RR: 0.97, 95% CI 0.89–1.07, $p=0.58$; I^2: 0%, $p=0.99$] [18, 23–31], and no significant age difference was noted (mean difference: 0 years, 95% CI − 1.66 to 1.67, $p=1$; I^2: 0%, $p=0.54$) [23–30]. There were no significant differences regarding the number of patients with ASA score III/IV [RLR: 122/235 (51.9%), OLR: 147/426 (34.5%), RR: 1.54, 95% CI 0.88–2.68, $p=0.13$; I^2:

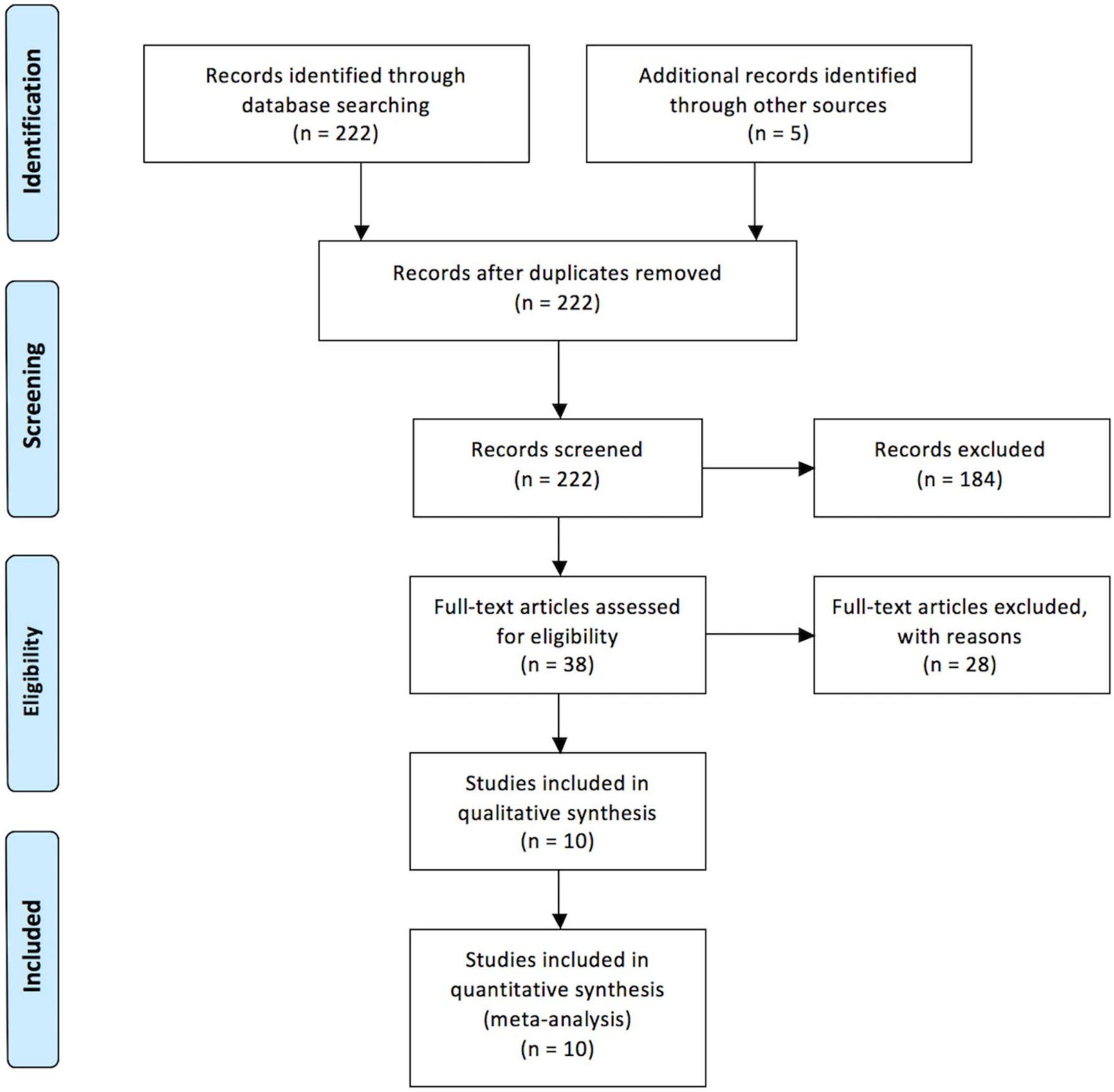

Fig. 1 Search flow diagram

86%, $p<0.00001$ (high heterogeneity)] [18, 24, 25, 28–30] and underlying cirrhosis [RLR: 44/122 (36.1%), OLR: 50/192 (26%), RR: 0.99, 95% CI 0.73–1.34, $p=0.95$; I^2: 0%, $p=0.61$] [23, 24, 27, 28]. Last, the percentage of patients that had a history of previous abdominal surgery was similar between the two groups [RLR: 124/273 (45.4%), OLR: 199/421 (47.3%), RR: 0.95, 95% CI 0.65–1.39, $p=0.79$]. However, the heterogeneity among studies was high I^2: 78%, $p=0.001$ [18, 25, 26, 29, 30].

Indications for resection

The indications for resection are shown in Table 1. There was no significant difference between RLR and OLR with regard to the number of liver tumors (mean difference: 0, 95% CI −0.44 to 0.44, $p=1$; I^2: 54%, $p=0.12$) [24, 26, 29]. However, patients treated with RLR had significantly smaller lesions compared to OLR patients (mean difference: −0.52 cm, 95% CI −0.96 to −0.08, $p=0.02$; I^2: 0%, $p=0.68$) [24, 26, 28, 29, 31]. Only three studies reported information concerning the location of ROLR lesions; sixteen were posterosuperior, whereas 47 were anterolateral.

Operative outcomes

Conversion rates to OLR ranged between 0 and 8.8% and the cumulative conversion rate was 4.6% (21/409) [18, 23, 25–28, 30, 31]. The two groups presented comparable rates of both major [RLR: 94/448 (21%), OLR: 128/737 (17.4%), RR: 0.86, 95% CI 0.64–1.15, $p=0.3$; I^2: 33%, $p=0.19$] and minor liver resections [RLR: 354/448 (79%), OLR: 609/737 (82.6%), RR: 1.01, 95% CI 0.97–1.04, $p=0.68$; I^2: 23%,

Table 1 Study characteristics

Author; year	Country	*n*	Type of study	MINORS	Type of lesion(s)	Major resection (> 3 segments)	AL/PS lesions	Conversion to OH (%)
RLR vs OLR								
Patriti; 2014	Italy	19 RLR vs. 69 OLR	Retrospective	18	HCC (1 vs. 15) LM (13 vs. 46) CCA (1 vs. 0) Benign/other[a] (4 vs 7) $p=0.002$	0 vs 0	3/16 vs. 21/48	N/A
Croner; 2016	Germany	10 RLR vs. 53 OLR	Retrospective	18	HCC (4 vs. 7) CC A1 vs. 2) LM (5 vs. 40) LA (0 vs. 3) FNH (0 vs. 1) $p=0.018$	N/A	N/A	N/A
Kingham; 2016	USA	64 RLR vs. 64 OLR	Retrospective	16	HCC (12 vs. 11) LM (35 vs. 36) GBC (3 vs. 4) $P=0.97$ Benign[a] (13 vs. 14)	6 vs. 6	N/A	4 (6.2%)
Lee; 2016	China	15 RLR vs. 42 OLR	Retrospective	17	Hepatolithiasis	5 vs. 15	N/A	0 (0%)
Sham; 2016	USA	71 RLR vs. 88 OLR	Retrospective	17	HCC (22 vs. 12) LM (24 vs. 40) CCA (14 vs. 31) Benign/other[a] (10 vs. 5)	17 vs. 33	N/A	4 (5.6%)
Chen; 2017	China	81 RLR vs. 81 OLR	Retrospective	18	HCC (81 vs. 81)	34 vs. 32	N/A	3 (1.6%)
Daskalaki; 2017	USA	68 RLR vs. 55 OLR	Retrospective	18	Benign and malignant[a] (68 vs 55)	29 vs. 24	N/A	6 (8.8%)
Morel; 2017	Switzerland	16 RLR vs. 16 OLR	Retrospective	19	HCC (8 vs. 5) LM (3 vs. 6) Benign[a] (5 vs. 5) $p=0.38$	0 vs. 0	16/0 vs. 16/0	0 (0%)
Wang; 2018	Taiwan	63 RLR vs. 177 OLR	Retrospective	22	HCC	3 vs. 8	N/A	0 (0%)
Nota; 2018	USA/Netherlands/South Korea	31 RLR vs. 31 OLR	Retrospective	18	HCC (11 vs. 14) LM (17 vs. 16) Benign[a] (2 vs. 1) HCC-CC (1 vs. 0)	0 vs. 0	0/31 vs. 0/31	2 (6%)

n; number of included patients, *MINORS* methodological index for non-randomized studies, *RLR* robotic liver resection, *OLR* open liver resection, *AL* anterolateral liver segment, *PS* posterosuperior liver segment, *HCC* hepatocellular carcinoma, *CCA* cholangiocarcinoma, *LA* Liver adenoma, *LM* liver metastasis, *FNH* focal nodular hyperplasia, *GBC* gallbladder cancer. *HCC-CC* mixed hepatocellular cholangiocarcinoma

[a]Not otherwise specified

$p=0.24$] [18, 23, 25–31]. With regard to R0 resections rates, these were found to be similar in the two groups (Fig. 2a) [RLR: 265/304 (87.2%), OLR: 551/605 (91.1%), RR: 1, 95% CI 0.97–1.02, $p=0.71$; I^2: 0%, $p=0.95$] [[18], [23, 24, 26, 28, 29, 31]]. No significant difference was detected in intraoperative transfusions between the two groups [RLR: 37/334 (11.1%), OLR: 66/415 (15.9%), RR: 0.91, 95% CI 0.4–2.08, $p=0.82$], although significant heterogeneity among the studies was encountered (I^2: 70%, $p=0.003$) [23, 25–30]. No difference was found in terms of estimated blood loss among the two groups (mean difference: −159.82 ml, 95% CI −342.45 to 22.81, $p=0.09$), whereas the heterogeneity

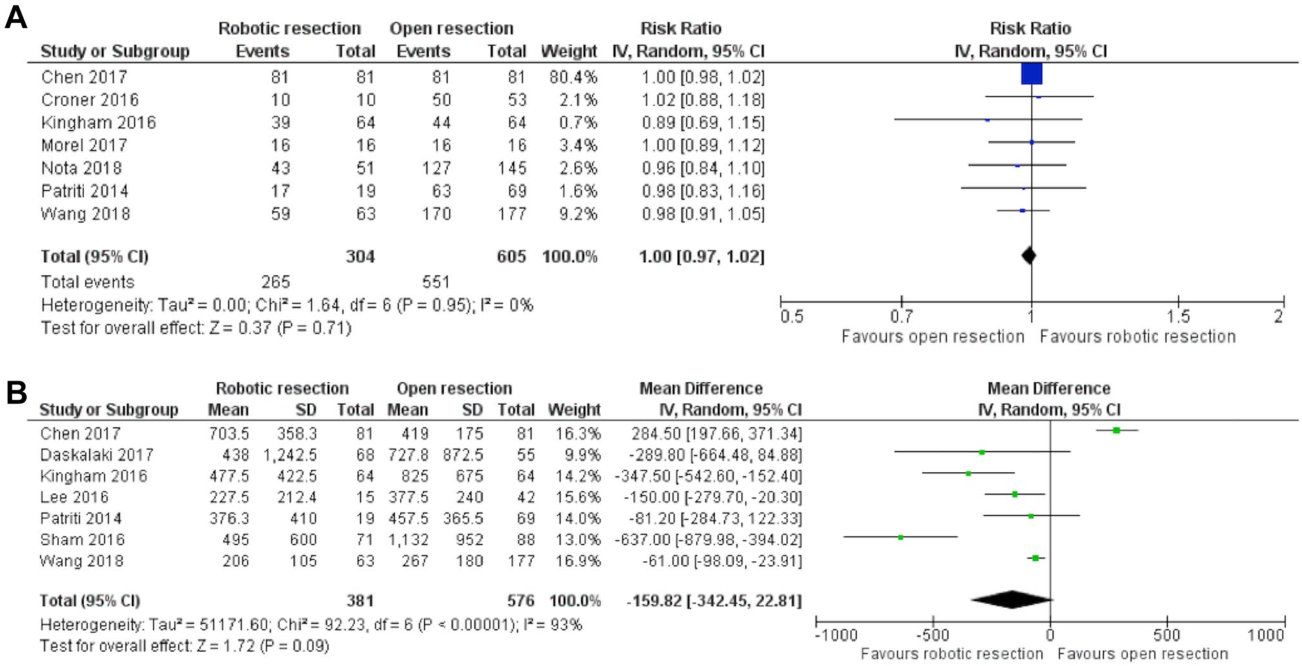

Fig. 2 Forest plot depicting **a** R0 resection and **b** estimated blood loss among the included studies

among studies was high (Fig. 2b) (I^2: 93%, $p<0.00001$) [23, 25–27, 29–31]. Total operative time was noted to be significantly higher in the RLR group (Fig. 3) (mean difference 65.91 min, 95% CI 22.39–109.44, $p=0.003$), with significant interstudy heterogeneity (I^2: 90%, $p<0.00001$) [23–31].

Postoperative outcomes

Postoperative mortality rates were equal between the two groups [RLR: 2/442 (0.5%), OLR: 3/774 (0.4%), RR: 0.78, 95% CI 0.15–3.99, $p=0.76$; I^2: 0%, $p=0.55$] [18, 23–27, 29–31]. Overall morbidity rates were found to be significantly lower in the RLR group (Fig. 4) [RLR: 63/407 (15.5%), OLR: 143/645 (22.2%), RR: 0.69, 95% CI 0.52–0.9, $p=0.006$; I^2: 0%, $p=0.7$] [23–31]. Morbidity subgroup analysis revealed that minor complications (Dindo–Clavien score I–II) were significantly lower in the RLR group [RLR: 43/392 (11%), OLR: 96/603 (15.9%), RR: 0.69, 95% CI 0.49–0.97, $p=0.03$; I^2: 0%, $p=0.93$], whereas for major complications (Dindo–Clavien score III–V) statistical significance was not attained (Fig. 5a, b) [RLR: 14/443 (3.2%), OLR: 41/748 (5.5%), RR: 0.58, 95% CI 0.32–1.05, $p=0.07$; I^2: 0%, $p=0.8$] [18, 23–26, 28–31]. Further analysis of specific postoperative complications revealed non-significant differences in postoperative bile leaks [RLR: 10/458 (2.2%), OLR: 21/790 (2.7%), RR: 0.85, 95% CI 0.4–1.8, $p=0.67$; I^2: 0%, $p=0.57$] [18, 23–31] and bleeding [RLR: 7/312 (2.2%), OLR: 15/523 (2.9%), RR: 1.07, 95% CI 0.46–2.48, $p=0.88$; I^2: 0%, $p=0.9$] [23–25, 29–31]. Finally,

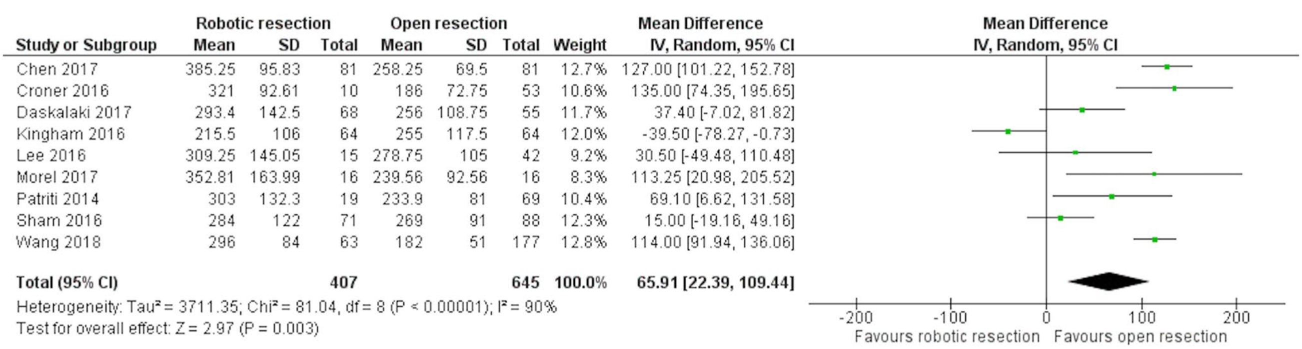

Fig. 3 Forest plot depicting operative times among the included studies

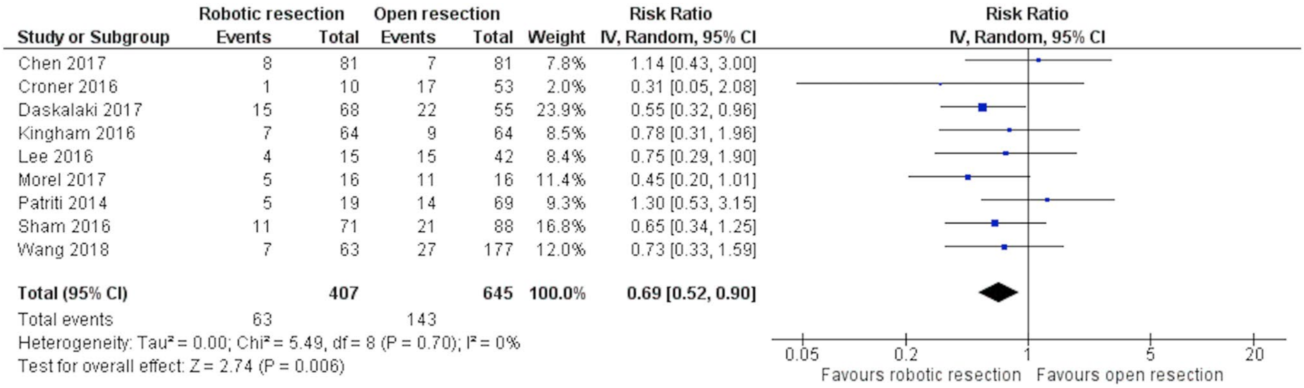

Fig. 4 Forest plot depicting overall morbidity among the included studies

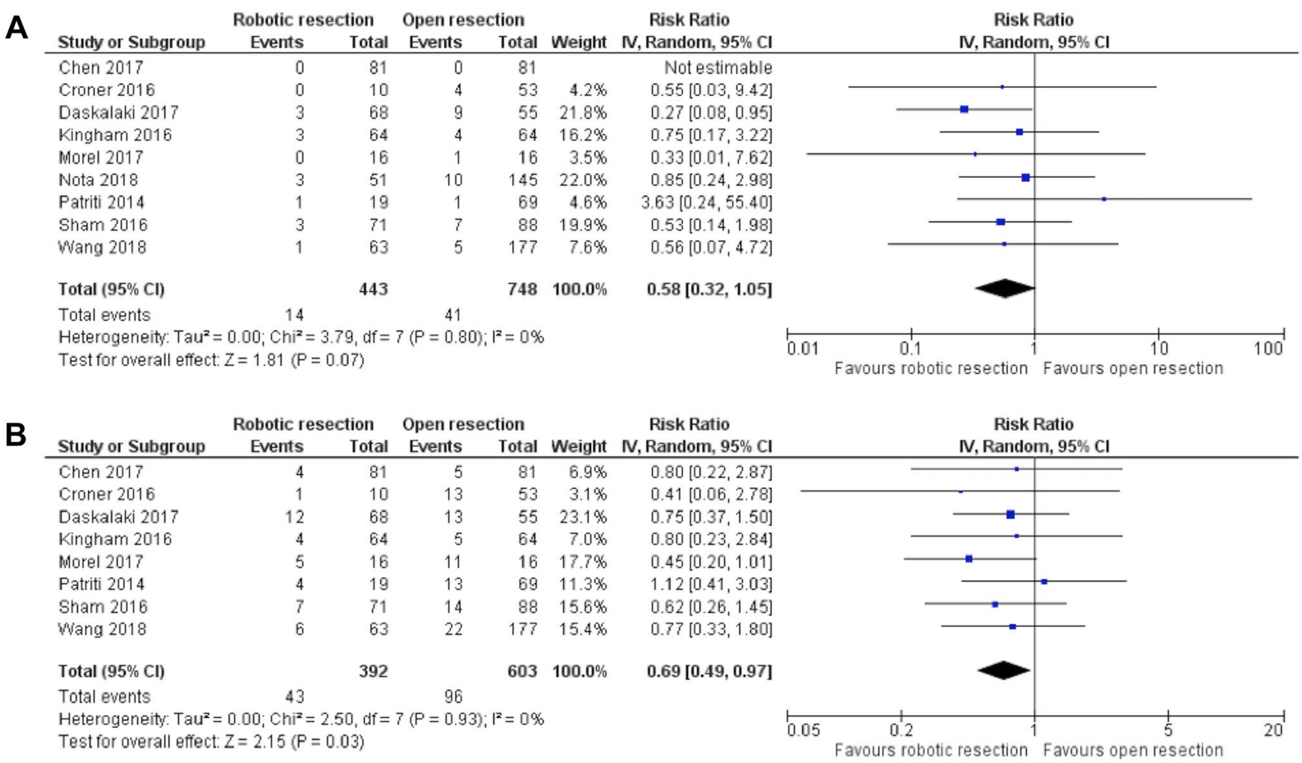

Fig. 5 Forest plot depicting **a** Dindo–Clavien III–IV complications and **b** Dindo–Clavien I–II complications among the included studies

length of hospital stay was lower in the RLR group [mean difference: −2.76 days, 95% CI −3.84 to −1.68, $p < 0.00001$], albeit significant heterogeneity among studies was appreciated (Fig. 6) (I^2: 61%, $p = 0.008$) [23–31].

Study or Subgroup	Robotic resection Mean	SD	Total	Open resection Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Chen 2017	11	3.83	81	16.8	6.167	81	14.1%	-5.80 [-7.38, -4.22]
Croner 2016	7	2.38	10	10	9.5	53	8.1%	-3.00 [-5.95, -0.05]
Daskalaki 2017	6.8	6.25	68	9.2	12	55	6.5%	-2.40 [-5.90, 1.10]
Kingham 2016	8.5	6	64	10.25	5.25	64	12.2%	-1.75 [-3.70, 0.20]
Lee 2016	9.5	5.575	15	11.75	5.25	42	7.2%	-2.25 [-5.49, 0.99]
Morel 2017	7.94	4.8	16	11	4.4	16	7.3%	-3.06 [-6.25, 0.13]
Patriti 2014	6.7	3	19	7.9	4.4	69	13.4%	-1.20 [-2.90, 0.50]
Sham 2016	3.9	2.3	71	7	6.4	88	14.8%	-3.10 [-4.54, -1.66]
Wang 2018	6.21	2.06	63	8.18	6.99	177	16.4%	-1.97 [-3.12, -0.82]
Total (95% CI)			**407**			**645**	**100.0%**	**-2.76 [-3.84, -1.68]**

Heterogeneity: Tau² = 1.51; Chi² = 20.68, df = 8 (P = 0.008); I² = 61%
Test for overall effect: Z = 5.00 (P < 0.00001)

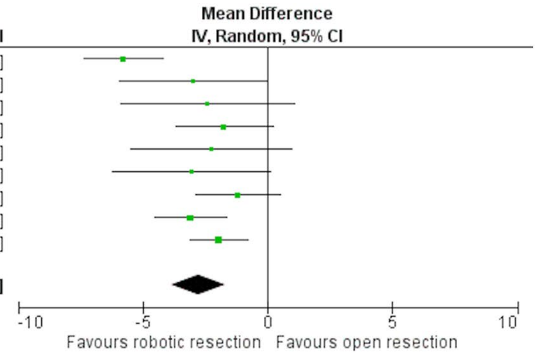

Fig. 6 Forest plot depicting length of stay among the included studies

Discussion

The present meta-analysis is an attempt to evaluate the safety and efficiency of RLR compared to the traditional open approach. Analysis of short-term postoperative outcomes demonstrated a clear advantage of the robotic over the traditional open approach with regard to overall morbidity and length of hospital stay. The total operative time was significantly higher in the RLR group, whereas operative outcomes between the two groups were comparable in terms of R0 resection rates, estimated blood loss and blood transfusion requirements. Conversions rates from RLR to OLR were relatively low and ranged from 0 to 8.8%, whereas mortality rates were not shown to be different between the two groups.

In terms of overall morbidity rates, patients undergoing RLR had fewer minor complications (Dindo–Clavien score I–II), whereas this effect was not evident for major complications (Dindo–Clavien score III–IV). This result underlines the non-inferiority of the robotic approach in terms of safety. On the contrary, the reduction in the rate of minor complications may be related to the reduction of total hospital stay, an effect that can be further explained by the advantages of minimally invasive surgery pertaining to earlier ambulation, less postoperative pain and reduced analgesic requirement [32, 33]. The significant heterogeneity among the included studies observed in terms of hospital stay could not be adequately interpreted due to inability to perform subgroup analysis. Moreover, shortened hospital stay is associated with reduced total costs, which may counterbalance the increased costs associated with a robotic liver procedure. This assumption is supported by the cost-effectiveness analysis presented by Daskalaki et al. [25], which showed that the total average cost of RLR is lower compared to conventional OLR, owing to the lower rates of ICU admissions and inpatient nursing and pharmacy costs. On the same note, Sham et al. in their study showed that despite the fact that RH perioperative costs were higher (\$6026 vs. \$5479; $p = 0.047$), the postoperative costs were significantly lower, and resulted in lower total hospital direct costs compared with OLR (\$14,754 vs. \$18,998; $p = 0.001$) [30]. Nevertheless, more such analyses are mandatory to draw safe conclusions.

The only previously published meta-analysis, which included seven studies, similarly to our meta-analysis demonstrated that RLR were associated with a shorter hospital stay ($p < 0.001$), lower overall complication ($p = 0.004$) and longer operative times ($p = 0.03$) compared to OLR [34]. However, contrary to the results of Wong et al., which indicated lower major (Dindo–Clavien III and above) complications in the RLR group vs. OLR, our meta-analysis showed no significant difference among the two groups with the addition of three more studies (Fig. 5a) [34].

Conversion to OLR rate ranged from 0 and 8.8%, with a cumulative conversion rate of 4.6%, based on eight studies. This finding comes in line with the average conversion rate reported in literature [12, 35], interestingly similar conversion rates have been reported for minor or even major LLR [36, 37]. Of note, the present conversion rates were extracted from patients undergoing both minor and major liver resections. More specifically 21.9% of patients (94 patients) underwent major RLR, which highlights the applicability of robotic surgery even in the setting of a major hepatectomy, with a high reproducibility as is evident by existing literature [16, 23, 36, 38–40]. Notwithstanding the ever-increasing body of literature on robotic major liver resections, the effect of the adequate experience involved needs to be better defined, with more challenging procedures reserved for the most experienced surgeons [41].

The outcomes of the present study indeed confirm the beneficial effect of minimally invasive surgery in the treatment of various hepatic lesions compared to the traditional open approach. Whatsoever, to better evaluate the impact of the robotic approach in the field one should take under account the comparison between RLR and LLR. A recently published meta-analysis which evaluated 13 studies and showed that RLR compared to LLR were associated with longer operative times, elevated intraoperative blood loss and higher economic costs [42]. Moreover, no differences were shown with regard to hospital length of stay, blood transfusion, complication, conversion and R0 resection rates. Notably, according to the authors, the difference shown in blood loss via the robotic approach could be attributed to the lack of equipment (ultrasonic dissector) and relatively lower surgeon experience. Of note, when subgroup analysis was performed, for minor liver resection and resections performed after 2010, no differences in blood loss were shown between RLR and LLR. The prolonged operative times were attributed in the lack of experience, high percentage of major liver resections and finally time length of docking/undocking the robot [42]. One could presume that despite the higher costs of RLR, it may allow for easier and safer resection of challenging segments, however, more studies are needed to evaluate such advantage.

The learning curves for performance of these minimally invasive procedures also need to be taken under account; unlike for the performance of LLR, it has been shown that learning curves for performance of RLR are shorter [43]; Efanov et al. compared learning curves in simple and complex liver resections either through the laparoscopic or robotic approach. According to their results, surgeons required at least 16 RLR of low and intermediate difficulty to progress to more complex procedures, whereas 29 LLR were required to advance to more complex procedures through the laparoscopic approach [43]. In another retrospective study of major RLR, the authors concluded that under the prism of careful patient selection and adequate training in the robotic platform an initial and intermediate phase of 15 and 25 cases, respectively, were found to overcome the learning curve for major RLR [41].

This meta-analysis has several limitations that need to be considered when interpreting the outcomes. First of all, the studies involved were single center and retrospective, with only two being case-matched comparisons. Moreover, the retrospective nature of studies unavoidably introduces the risk of selection bias. It is also critical to acknowledge the interstudy variability in the institution and surgeons' experience with robotic liver surgery, a fact that is impossible to quantify and evaluate. Moreover, the heterogeneity of tumor type and localization as well as extent of liver resections in both groups suggest a critical limitation that may significantly have impacted the outcomes. Moreover, heterogeneity among the included studies with regard to intraoperative transfusions, blood loss, operative times, and hospital stay must be taken under account. Finally, analysis of long-term outcomes is lacking.

In conclusion, the present review suggests that RLR is a safe and efficient approach with advantages over conventional open liver surgery with regard to overall morbidity and hospital stay. With continuous accrual of experience in the filed of robotic surgery and the ongoing development of surgical strategies, the beneficial effects of robotic liver surgery can be widely expected in future studies. Further, well-designed prospective trials are mandatory to clearly determine the value of robotic surgery in clinical practice, as well as to further specify the cost-effectiveness of this approach.

Compliance with ethical standards

Conflict of interest The authors of this study declare no conflict of interest. The authors of this study declare no financial support.

Ethical approval The article is in accordance with ethical standards.

Research involving human participants and/or animals This study does not contain any study with human participants performed by any of the authors.

Informed consent None.

References

1. Jones C, Kelliher L, Dickinson M, Riga A, Worthington T, Scott MJ et al (2013) Randomized clinical trial on enhanced recovery versus standard care following open liver resection. Br J Surg 100(8):1015–1024. https://doi.org/10.1002/bjs.9165
2. Mavros MN, de Jong M, Dogeas E, Hyder O, Pawlik TM (2013) Impact of complications on long-term survival after resection of colorectal liver metastases. Br J Surg 100(5):711–718. https://doi.org/10.1002/bjs.9060
3. Machairas N, Prodromidou A, Kostakis ID, Spartalis E, Sotiropoulos GC (2018) Safety and efficacy of laparoscopic liver resection for lesions located on posterosuperior segments: a meta-analysis of short-term outcomes. Surg Laparosc Endosc Percutan Tech 28(4):203–208. https://doi.org/10.1097/SLE.0000000000000562
4. Sotiropoulos GC, Machairas N, Stamopoulos P, Kostakis ID, Dimitroulis D, Mantas D et al (2016) Laparoscopic versus open liver resection for hepatocellular carcinoma: initial experience in Greece. Ann Gastroenterol 29(4):521–529. https://doi.org/10.20524/aog.2016.0067
5. Sotiropoulos GC, Prodromidou A, Machairas N (2017) Meta-analysis of laparoscopic vs open liver resection for hepatocellular carcinoma: the European experience. J BUON 22(5):1160–1171
6. Machairas N, Papaconstantinou D, Stamopoulos P, Prodromidou A, Garoufalia Z, Spartalis E et al (2018) The emerging role of laparoscopic liver resection in the treatment of recurrent hepatocellular carcinoma: a systematic review. Anticancer Res 38(5):3181–3186. https://doi.org/10.21873/anticanres.12582
7. Moris D, Tsilimigras DI, Machairas N, Merath K, Cerullo M, Hasemaki N et al (2019) Laparoscopic synchronous resection of colorectal cancer and liver metastases: a systematic review. J Surg Oncol 119(1):30–39. https://doi.org/10.1002/jso.25313
8. Sotiropoulos GC, Prodromidou A, Kostakis ID, Machairas N (2017) Meta-analysis of laparoscopic vs open liver resection for hepatocellular carcinoma. Updates Surg 69(3):291–311. https://doi.org/10.1007/s13304-017-0421-4
9. Ciria R, Cherqui D, Geller DA, Briceno J, Wakabayashi G (2016) Comparative short-term benefits of laparoscopic liver

resection: 9000 cases and climbing. Ann Surg 263(4):761–777. https://doi.org/10.1097/SLA.0000000000001413
10. Machairas N, Sotiropoulos GC (2018) Diffusion of laparoscopic liver resections: are we there yet? Laparosc Surg 2:14. https://doi.org/10.21037/ls.2018.04.01
11. Ballantyne GH (2002) The pitfalls of laparoscopic surgery: challenges for robotics and telerobotic surgery. Surg Laparosc Endosc Percutan Tech 12(1):1–5
12. Tsilimigras DI, Moris D, Vagios S, Merath K, Pawlik TM (2018) Safety and oncologic outcomes of robotic liver resections: a systematic review. J Surg Oncol 117(7):1517–1530. https://doi.org/10.1002/jso.25018
13. Marino MV, Gulotta G, Komorowski AL (2018) Fully robotic left hepatectomy for malignant tumor: technique and initial results. Updates Surg. https://doi.org/10.1007/s13304-018-0560-2
14. Choi GH, Choi SH, Kim SH, Hwang HK, Kang CM, Choi JS et al (2012) Robotic liver resection: technique and results of 30 consecutive procedures. Surg Endosc 26(8):2247–2258. https://doi.org/10.1007/s00464-012-2168-9
15. Zhang X, Wei Z, Bie M, Peng X, Chen C (2016) Robot-assisted versus laparoscopic-assisted surgery for colorectal cancer: a meta-analysis. Surg Endosc 30(12):5601–5614. https://doi.org/10.1007/s00464-016-4892-z
16. Boggi U, Caniglia F, Amorese G (2014) Laparoscopic robot-assisted major hepatectomy. J Hepatobiliary Pancreat Sci 21(1):3–10. https://doi.org/10.1002/jhbp.34
17. Wu CY, Chen PD, Lee CY, Liang JT, Wu YM (2018) Robotic-assisted right posterior segmentectomies for liver lesions: single-center experience of an evolutional method in left semilateral position. J Robot Surg. https://doi.org/10.1007/s11701-018-0842-1
18. Nota CL, Woo Y, Raoof M, Boerner T, Molenaar IQ, Choi GH et al (2018) Robotic versus open minor liver resections of the posterosuperior segments: a multinational, propensity score-matched study. Ann Surg Oncol. https://doi.org/10.1245/s10434-018-6928-1
19. Boggi U, Caniglia F, Vistoli F, Costa F, Pieroni E, Perrone VG (2015) Laparoscopic robot-assisted resection of tumors located in posterosuperior liver segments. Updates Surg 67(2):177–183. https://doi.org/10.1007/s13304-015-0304-5
20. Moher D, Liberati A, Tetzlaff J, Altman DG (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 6(7):e1000097. https://doi.org/10.1371/journal.pmed.1000097
21. Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J (2003) Methodological index for non-randomized studies (minors): development and validation of a new instrument. ANZ J Surg 73(9):712–716
22. Hozo SP, Djulbegovic B, Hozo I (2005) Estimating the mean and variance from the median, range, and the size of a sample. BMC Med Res Methodol 5:13. https://doi.org/10.1186/1471-2288-5-13
23. Chen PD, Wu CY, Hu RH, Chou WH, Lai HS, Liang JT et al (2017) Robotic versus open hepatectomy for hepatocellular carcinoma: a matched comparison. Ann Surg Oncol 24(4):1021–1028. https://doi.org/10.1245/s10434-016-5638-9
24. Croner RS, Perrakis A, Hohenberger W, Brunner M (2016) Robotic liver surgery for minor hepatic resections: a comparison with laparoscopic and open standard procedures. Langenbeck's Arch Surg 401(5):707–714. https://doi.org/10.1007/s00423-016-1440-1
25. Daskalaki D, Gonzalez-Heredia R, Brown M, Bianco FM, Tzvetanov I, Davis M et al (2017) Financial impact of the robotic approach in liver surgery: a comparative study of clinical outcomes and costs between the robotic and open technique in a single institution. J Laparoendosc Adv Surg Tech Part A 27(4):375–382. https://doi.org/10.1089/lap.2016.0576
26. Kingham TP, Leung U, Kuk D, Gonen M, D'Angelica MI, Allen PJ et al (2016) Robotic liver resection: a case-matched comparison. World J Surg 40(6):1422–1428. https://doi.org/10.1007/s00268-016-3446-9
27. Lee KF, Fong AK, Chong CC, Cheung SY, Wong J, Lai PB (2016) Robotic liver resection for primary hepatolithiasis: is it beneficial? World J Surg 40(10):2490–2496. https://doi.org/10.1007/s00268-016-3528-8
28. Morel P, Jung M, Cornateanu S, Buehler L, Majno P, Toso C et al (2017) Robotic versus open liver resections: a case-matched comparison. Int J Med Robot Comput Assist Surg. https://doi.org/10.1002/rcs.1800
29. Patriti A, Cipriani F, Ratti F, Bartoli A, Ceccarelli G, Casciola L et al (2014) Robot-assisted versus open liver resection in the right posterior section. J Soc Laparoendosc Surg. https://doi.org/10.4293/jsls.2014.00040
30. Sham JG, Richards MK, Seo YD, Pillarisetty VG, Yeung RS, Park JO (2016) Efficacy and cost of robotic hepatectomy: is the robot cost-prohibitive? J Robot Surg 10(4):307–313. https://doi.org/10.1007/s11701-016-0598-4
31. Wang WH, Kuo KK, Wang SN, Lee KT (2018) Oncological and surgical result of hepatoma after robot surgery. Surg Endosc 32(9):3918–3924. https://doi.org/10.1007/s00464-018-6131-2
32. Ahmed EA, Montalti R, Nicolini D, Vincenzi P, Coletta M, Vecchi A et al (2016) Fast track program in liver resection: a PRISMA-compliant systematic review and meta-analysis. Medicine 95(28):e4154. https://doi.org/10.1097/md.0000000000004154
33. Chen PD, Wu CY, Hu RH, Ho CM (2016) Robotic liver donor right hepatectomy: a pure, minimally invasive approach. Liver Transpl 22(11):1509–1518. https://doi.org/10.1002/lt.24522
34. Wong DJ, Wong MJ, Choi GH, Wu YM, Lai PB, Goh BKP (2018) Systematic review and meta-analysis of robotic versus open hepatectomy. ANZ J Surg. https://doi.org/10.1111/ans.14690
35. Qiu J, Chen S, Chengyou D (2016) A systematic review of robotic-assisted liver resection and meta-analysis of robotic versus laparoscopic hepatectomy for hepatic neoplasms. Surg Endosc 30(3):862–875. https://doi.org/10.1007/s00464-015-4306-7
36. Tsung A, Geller DA, Sukato DC, Sabbaghian S, Tohme S, Steel J et al (2014) Robotic versus laparoscopic hepatectomy: a matched comparison. Ann Surg 259(3):549–555. https://doi.org/10.1097/sla.0000000000000250
37. Hu L, Yao L, Li X, Jin P, Yang K, Guo T (2018) Effectiveness and safety of robotic-assisted versus laparoscopic hepatectomy for liver neoplasms: a meta-analysis of retrospective studies. Asian J Surg 41(5):401–416. https://doi.org/10.1016/j.asjsur.2017.07.001
38. Giulianotti PC, Sbrana F, Coratti A, Bianco FM, Addeo P, Buchs NC et al (2011) Totally robotic right hepatectomy: surgical technique and outcomes. Arch Surg 146(7):844–850. https://doi.org/10.1001/archsurg.2011.145
39. Wu YM, Hu RH, Lai HS, Lee PH (2014) Robotic-assisted minimally invasive liver resection. Asian J Surg 37(2):53–57. https://doi.org/10.1016/j.asjsur.2014.01.015
40. Spampinato MG, Coratti A, Bianco L, Caniglia F, Laurenzi A, Puleo F et al (2014) Perioperative outcomes of laparoscopic and robot-assisted major hepatectomies: an Italian multi-institutional comparative study. Surg Endosc 28(10):2973–2979. https://doi.org/10.1007/s00464-014-3560-4
41. Chen PD, Wu CY, Hu RH, Chen CN, Yuan RH, Liang JT et al (2017) Robotic major hepatectomy: is there a learning

curve? Surgery 161(3):642–649. https://doi.org/10.1016/j.surg.2016.09.025
42. Guan R, Chen Y, Yang K, Ma D, Gong X, Shen B et al (2019) Clinical efficacy of robot-assisted versus laparoscopic liver resection: a meta analysis. Asian J Surg 42(1):19–31. https://doi.org/10.1016/j.asjsur.2018.05.008
43. Efanov M, Alikhanov R, Tsvirkun V, Kazakov I, Melekhina O, Kim P et al (2017) Comparative analysis of learning curve in complex robot-assisted and laparoscopic liver resection. HPB 19(9):818–824. https://doi.org/10.1016/j.hpb.2017.05.003