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GUIDELINES

International consensus statement on robotic hepatectomy surgery in 2018

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Abstract

The robotic surgical system has been applied in liver surgery. However, controversies concerns exist regarding a variety of factors including the safety, feasibility, efficacy, and cost-effectiveness of robotic surgery. To promote the development of robotic hepatectomy, this study aimed to evaluate the current status of robotic hepatectomy and provide sixty experts' consensus and recommendations to promote its development. Based on the World Health Organization Handbook for Guideline Development, a Consensus Steering Group and a Consensus Development Group were established to determine the topics, prepare evidence-based documents, and generate recommendations. The GRADE Grid method and Delphi vote were used to formulate the recommendations. A total of 22 topics were prepared analyzed and widely discussed during the 4 meetings. Based on the published articles and expert panel opinion, 7 recommendations were generated by the GRADE method using an evidence-based method, which focused on the safety, feasibility, indication, techniques and cost-effectiveness of hepatectomy. Given that the current evidences were low to very low as evaluated by the GRADE method, further randomized-controlled trials are needed in the future to validate these recommendations.

Key words: Minimally invasive surgery; Robotic hepatectomy; Laparoscopic hepatectomy; Hepatectomy resection; Consensus statement

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Core tip: The robotic surgical system has been applied in liver surgery. Liver surgeons are also attempting to gradually expand the indications of robotic hepatectomy. To promote the development and standardization of robotic hepatectomy, we identified a group of robotic surgeon experts to provide clinical statements. Based on the published articles and expert panel opinion, 7 recommendations were generated by the GRADE method using an evidence-based method and focused on the safety, feasibility, indication, techniques and cost-effectiveness of hepatectomy. Since the current evidences were low to very low as evaluated by the GRADE method, further randomized controlled trials are needed in the future to validate these recommendations.

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INTRODUCTION

In 1987, Mouret performed the first laparoscopic cholecystectomy, which started the era of minimally invasive hepatobiliary surgery[1]. In the 1990s, the use of laparoscopic hepatectomy for benign and malignant tumors was independently reported by Katkhouda, Reich, and others[2,3]. After decades of development, the application of laparoscopic techniques in hepatectomy has become more mature. In 2008, the first consensus guidelines for laparoscopic hepatectomy were published in Louisville, signifying the gradual standardization of minimally invasive hepatectomy[4]. Meanwhile, with the advancement of technology, robot-assisted laparoscopic surgical systems have also continuously evolved. In 1997, Himpens *et al*[5] successfully performed robotic cholecystectomy, and this new type of laparoscopic surgical systems began to be implemented in clinical practice. In 2000, the new generation da Vinci robotic surgical system was officially approved by the United States Food and Drug Administration and was then gradually accepted by surgeons. Robot-assisted laparoscopic surgical systems possess advantages, such as providing a clear, stable, and magnified field of vision, flexibility, it is ergonomic, and has a tremor filter. Specifically, the flexibility and the clear and stable vision have overcome the major disadvantages of conventional laparoscopy. However, the absence of tactile feedback, high cost of mainstream models, and the lack of available surgical instruments, also limit its clinical development and application.

In 2003, Professor Giulianotti *et al*[6-11] reported for the first time the application of robot-assisted laparoscopic system in segmental hepatic resection. Since then, countries such as the United States, Europe, China, South Korea, Singapore, Russia, India, and Brazil have reported their own experience on robotic hepatectomy. For example, in China, the Da Vinci robot-assisted laparoscopic surgical system has completed 26765 operations in mainland China as of 2017, which is more than 5 times the number of completed cases in 2014 (4982 operations). The annual growth rate is approximately 45%, with robotic hepatobiliary surgery accounting for approximately 10% of the total number of robotic operations.

Meanwhile, liver surgeons are also attempting to gradually expand the indications of robotic hepatectomy. The earliest cases of robotic hepatectomy included wedge hepatectomy, hemihepatectomy, and extended hemihepatectomy. Some surgeons also utilized robotic hepatectomy to perform segmental resection of posterosuperior segments, liver donor hepatectomy, and the associating liver partition with portal vein ligation for staged hepatectomy[12-16]. However, due to the complexity of the techniques involved in liver surgery, the implementation and popularization of minimally invasive hepatectomy, including robotic hepatectomy, has remained challenging. In 2014, a nationwide survey on hepatectomy conducted by the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) showed that minimally-invasive hepatectomy accounted for 17.9% of all hepatectomy cases in the United States, of which robotic hepatectomy merely accounted for 5.3% of minimally invasive hepatectomy cases[17]. According to the statistics reported by the Italian National Survey Study Group, between January 1, 1995 and February 28, 2012, the proportion of minimally-invasive hepatectomy was approximately 10.3%[18]. A retrospective analysis of a large surgical oncology program conducted by the University of Pittsburgh Medical Center between 2009 and 2014 (1236 surgeries were analyzed, including 157 robotic liver surgeries) showed that the conversion rate was 3.1%, overall incidence rate of complications was 18.6%, and 90-day mortality rate was 1.1%. Among cases of perioperative mortality, 91% were from robotic hepatobiliary procedures. For robotic liver/bile duct procedures, the incidence of complications was 26.1%, mortality rate was 3.2%, and conversion rate was 7.6%, which were all above the overall mean values of robotic procedures[19]. Buchs *et al*[20] analyzed 884 cases of robotic surgery performed at the University of Illinois Hospital between April 2007 and June 2010 and found that hepatectomy was considered as an advanced robotic procedure, and multivariate analysis showed that advanced procedure was a factor significantly associated with a higher risk for complications.

Although most reports to date show that robotic hepatectomy are safe, feasible and effective, the majority of these studies are case reports and case series from high-volume centers. There are relatively few case-control studies with large sample sizes, and high-quality randomized controlled studies are lacking[6,11,21-56]. According to the findings of current studies, the effectiveness of robotic hepatectomy is essentially identical to that of open surgery and traditional laparoscopic hepatectomy. However, conclusions on operative time, intraoperative blood loss, conversion rate, incidence of postoperative complications, and overall cost-benefit ratio remain divided in different reports, with the main controversy surrounding the application of certain procedure modalities. These factors severely limit the application of robotic hepatectomy[6,21,23,24,31,32,36,37,39,42,57]. Some researchers have pointed out that it is undesirable to simply increase economic expenses and aggressively apply robot-assisted laparoscopic surgical system for procedures such as living-donor hepatectomy while therapeutic efficacy is not improved[58-61]. Other opinions point out that as a developing and advancing surgical technology,robotic surgery will become effective enough to allow us to correct any complications with its own techniques[62].

To promote the development and standardization of robotic hepatectomy and improve patient safety, we identified a group of robotic surgeon experts (based on the number of robotic liver surgeries and published papers to screen experts with international influence) to provide clinical statements related to robotic surgery. We searched the online databases for published articles related to robotic surgery; with evidence-based methods. All evidences were graded using the GRADE system and upgraded or downgraded after integrating experts' opinions until a final consensus was reached.

METHODS

We referred to the World Health Organization Handbook for Guideline Development and established the Consensus Steering Group, consisting of five experts in the field from all around the world, with the following missions: To (1) approve the use of PICOs (population, intervention, comparator, outcomes); (2) supervise the literature search and systematic reviews; (3) check the grade of the evidence; (4) draft the final recommendations using a modified Delphi approach; and (5) approve the publication of the consensus. The Consensus Development Group is a multidisciplinary group of 30 experts, including clinicians, methodologists, and economists, with the following missions: To (1) define the scope of the consensus, draft the PICOs; (2) grade the quality of the evidence; (3) draft preliminary recommendations; (4) write the draft consensus; and (5) publish and promote the consensus. The Consensus Secretary Group is responsible for conducting systematic reviews and investigation of patients' views and preferences, along with the Chinese GRADE Center, for providing methodological support. All members of the Consensus Steering Group and the Consensus Secretary Group were required to disclose potential conflicts of interest, which were reviewed by the chairs. No relevant conflicts of interest were noted.

We have held 4 meetings until now on questions focusing on hepato-pancreato-biliary minimally invasive surgery, in Beijing (April, 2017), Lanzhou (October, 2017), Beijing (April, 2018), and Hong Kong (October, 2018) involving more than 60 clinical experts. Finally, we formulated sixteen PICO questions for the consensus. Published articles and conference abstracts were identified from PubMed, Embase, the Cochrane Library. Additionally, we used the GRADE approach to rate the quality of evidence and the strength of recommendation. The experts in the Consensus Development Group voted on the recommendations according to the quality of evidence, patients' views and preferences, and economic evaluation. The GRADE Grid method and Delphi vote were used to formulate the recommendations. Three rounds of voting were conducted. When 70% of the experts approved a recommendation, a consensus was assumed to have been reached.

The formulated recommendations were submitted to 24 experts, who have a broad clinical experience in hepatobiliary minimally invasive surgery. The external reviewers were not involved in the development of the consensus. The Consensus Steering Group discussed the external reviews in a meeting and revised the recommendations based on this feedback (Table 1). The Consensus Steering Group plans to update the guideline again before 2022. A flow chart describes the process of the consensus development (Figure 1)

Recommendation 1*: *Robotic hepatectomy is as safe and feasible as traditional open hepatectomy. Robotic hepatectomy has longer operative time, less intraoperative blood loss, less length of hospital stays, lower complication rate and lower severe

Table 1 2018 International statement on robotic hepatectomy

	Recommendation	Grade
1	RH is as safe and feasible as traditional OH. RH has longer operative time, less intraoperative blood loss, LOS, lower complication rate and lower severe complication rate. The intraoperative blood loss of RH is comparable to that of OH.	2C
2	RH has similar effectiveness for liver malignancy lesion compared to OH. Regarding the oncological outcome there is no significant difference in the radical resection rate, overall survival rate and recurrence rate between RH and OH.	2D
3	As a minimally invasive surgery, RH is as safe and feasible as traditional LH. RH has longer operative time, more intraoperative blood loss, and higher cost. RH has similar overall complication rate and LOS compared to OH. Conversion rate of RH would decrease with the experience accumulation.	2D
4	As minimally invasive surgery, RH has similar effectiveness for liver malignancy disease compared to LH. Regarding the oncological outcome there is no significant difference in the radical resection rate, overall survival rate and recurrence rate between RH and LH.	2D
5	For minor hepatectomy, RH as safe and feasible as LH and OH. RH has longer operative time than LH for minor hepatectomy. The intraoperative blood loss, overall postoperative complication rate and overall cost of robotic minor hepatectomy are comparable to that of laparoscopic minor hepatectomy.	2D
6	For major hepatectomy, RH as safe and feasible as LH and OH. RH has longer operative time than LH for major hepatectomy. The intraoperative blood loss, overall postoperative complication rate and overall cost of robotic major hepatectomy are comparable to that of laparoscopic major hepatectomy. There is no significant difference in the operative time, intraoperative blood loss and complication rate between RH and OH for minor hepatectomy.	2D
7	Robotic liver donor hepatectomy could be an alternative. The procedure should only be performed by experienced surgeons, and the true benefits of robotic donor hepatectomy need further investigation in the future.	2D

RH: Robotic hepatectomy; OH: Open hepatectomy; LH: Laparoscopic hepatectomy; LOS: Length of hospital stay.

complication rate. The intraoperative blood loss of robotic hepatectomy is comparable to that of open hepatectomy. The level of evidence: low. Level of recommendation: Weak (Grade 2C)

Although the volume of minimally-invasive hepatectomy has been increasing each year since the minimally-invasive technique was applied in hepatectomy in the 1990s, in the United States and Italy, minimally-invasive hepatectomy merely accounts for 17.9% and 10.3% of hepatectomy cases, respectively[17,18]. When subjected to the technical limitations of conventional laparoscopy, from the perspective of operative difficulty, most procedures are still mainly focused on the less complex minimally invasive wedge resection/segmentectomy (44.9%) and minimally-invasive left lateral sectionectomy (20.3%)[63,64]. The robot-assisted laparoscopic systems overcome the disadvantages of conventional laparoscopy by providing flexibility and sharp field of vision, but the lack of feedback and high cost have also led to some controversies regarding their applications. Compared with open hepatectomy, robotic hepatectomy is characterized by longer operative time, less intraoperative blood loss, lower blood transfusion rate, less length of hospital stays (LOS), and lower complication rate[32,36,44,65,66].

Wong *et al*[23] reported a meta-analysis of 7 retrospective, case-control studies on robotic and open hepatectomy conducted between 2013 and 2016. The analysis evaluated the intraoperative and short-term postoperative outcome in 329 cases of

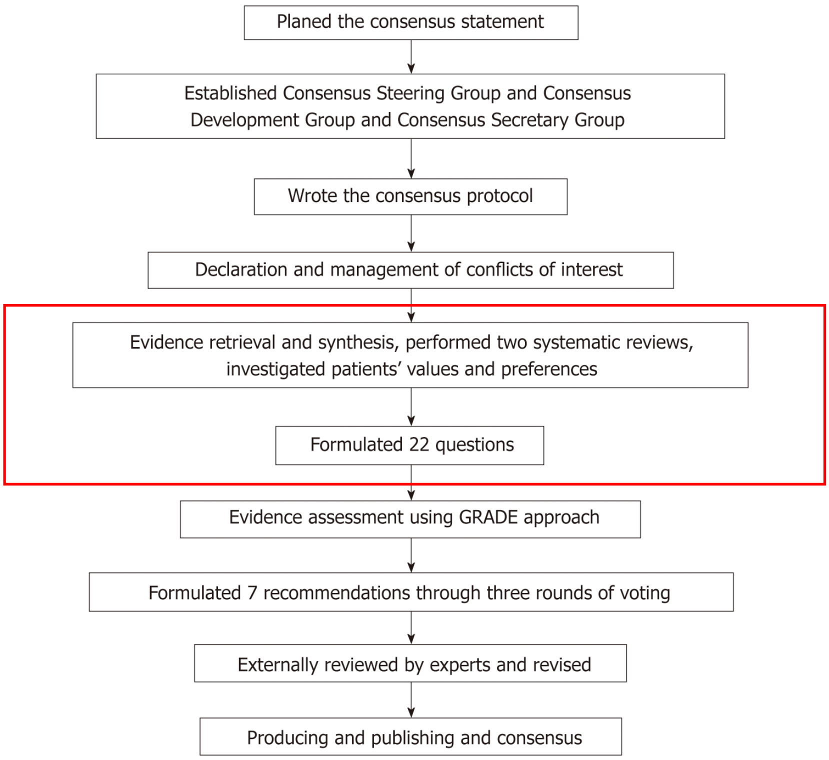

Figure 1 Flow chart describes the process of the consensus development.

robotic hepatectomy and 426 cases of open hepatectomy in Italy, the United States, Switzerland, and China. The results revealed that compared with open hepatectomy: Regarding intraoperative parameters, robotic hepatectomy had a longer operative time [mean difference (MD) = 61.47 min; 95% confidence interval (CI): 7.03, 115.91], but there were no significant differences in intraoperative blood loss (MD = 220.44 mL; 95%CI: -447.47, 6.58), blood transfusion rate [risk ratio (RR) = 0.78; 95%CI: 0.33, 1.83], and Pringle maneuver usage (RR= 0.98; 95%CI: 0.09, 11.34). The mean conversion rate of patients in the robotic surgery group in these studies was 4.4%; regarding short-term postoperative outcome, robotic hepatectomy led to shorter LOS (MD = -2.57 d; 95%CI: -3.31, -1.82), lower overall complications rate (RR = 0.63; 95%CI: 0.46, 0.86), and lower major (Clavien-Dindo grade III or higher[67]) complication rate (RR = 0.45; 95%CI: 0.22, 0.94).

Although it was previously believed that high cost is a major disadvantage of robotic hepatectomy, only a few reports have compared the cost of the 2 approaches and the conclusions are inconsistent. To date, the report with the largest sample size is published by Sham *et al*[65], who compared the cost of robotic hepatectomy (n = 71) and open hepatectomy (n = 88); their study was conducted in at a single center between 2011 and 2015. The results showed that although the perioperative costs were higher in the robotic surgery group (6026 *vs* 5479$, P = 0.047), the postoperative costs were lower (68570 *vs* 13425$, P < 0.001), and the total cost was lower (14754 *vs* 18998$, P < 0.001).

Daskalaki *et al*[32] compared patients admitted to a single center between 2009 and 2013 and found that compared with the conventional open hepatectomy (n = 55), the total cost of the robotic group (n = 68) was slightly lower (36040$ *vs* 39924$, T-Stat = -0.79). In contrast, Xu *et al*[68] compared the efficacy of robotic hepatectomy and open hepatectomy for the treatment of hilar cholangiocarcinoma in a single center between 2009 and 2012, and the results showed that compared with open hepatectomy (n = 32), the surgical costs were higher in the robotic group (n = 10) (272427$ ± 21316$ *vs* 15282$ ± 5957$, P = 0.018).

Recommendation 2: Robotic hepatectomy has similar effectiveness for liver malignancy lesion compared to open hepatectomy. Regarding the oncological outcome there is no significant difference in the radical resection rate, overall survival rate and recurrence rate between robotic hepatectomy and open hepatectomy. Level of recommendation: Very low. Level of recommendation: Weak (Grade 2D)

Open hepatectomy is currently the standard for surgical treatment of liver cancer.

There is yet to be a large-scale randomized controlled trial comparing the efficacy of robotic hepatectomy and open hepatectomy in malignant tumors, and most studies have been retrospective, case-control studies. Hepatocellular carcinoma is the most common primary malignant tumor of the liver.

In 2013, Lai *et al*[69] reported that among patients with hepatocellular carcinoma who received robotic hepatectomy, the R0 resection rate was 93%. After a median follow up of 14 mo, the 2-year overall and disease-free survival was 94%, and 74%, respectively. In the most recent single-center study published by Wang *et al*[66] in 2018, the follow-up results in patients newly diagnosed with hepatocellular carcinoma who underwent robotic hepatectomy (n = 63) and open hepatectomy (n =177) between June 2013 and July 2016 showed that the 2 approaches had no significant differences with regard to the R0 resection rate (93.7% *vs* 96%, P = 0.56), overall recurrence rate (27% *vs* 37.3%, P = 0.140), and survival time (760.47 ± 317.94 *vs* 686.89 ± 271.81 d, P = 0.115). The follow-up data showed that the robotic and open hepatectomy groups had no significant differences in the 1-year, 2-year, and 3-year disease-free survival (72.5%, 64.3%, 61.6% *vs* 77.8%, 71.9%, 71.9%, P = 0.325) and overall survival (95.4%, 92.3%, 92.3% *vs* 100%, 97.7%, 97.7%, P = 0.137). Regarding patients with hepatocellular carcinoma and negative resection margins, the follow-up study published by Chen *et al*[31] in 2017 evaluated patients with newly diagnosed hepatocellular carcinoma with negative margin (R0 resection) after undergoing robotic hepatectomy (n = 81) and open hepatectomy (n = 81) at a single center between January 2012 and October 2015. The results showed that the robotic and open hepatectomy groups had no significant differences in the 1-year, 2-year, and 3-year disease-free survival (91.5%, 84.3%, 72.2% *vs* 79.2%, 73.0%, 58%, P = 0.062) and overall survival (100%, 97.8%, 92.6% *vs* 100%, 98.4%, 92.6%, P = 0.431).

Recommendation 3: As a minimally invasive surgery, robotic hepatectomy is as safe and feasible as traditional laparoscopic hepatectomy. Robotic hepatectomy has longer operative time, more intraoperative blood loss, and higher cost. Robotic hepatectomy has similar overall complication rate and length of hospital stays compared to open hepatectomy. Conversion rate of robotic hepatectomy would decrease with the experience accumulation. Level of evidence: Very low. Level of recommendation: Weak (Grade 2D)

Data from the ACS NSQIP showed that between 2000 and 2011, robotic liver surgery accounted for 7.4% of all minimally invasive liver surgeries[70]. In 2010, Berber *et al*[56] from the Cleveland Clinic in the United States was the first to compare robotic hepatectomy (n = 9) and conventional laparoscopic hepatectomy (n = 23) at single center. The results showed that the two groups had no significant differences in operative time (259 ± 28 *vs* 234 ± 17 min, P = 0.6), intraoperative blood loss (136 ± 61 *vs* 155±54 mL), and resection margin (11±8 vs. 14 ± 10 mm). Guan *et al*[71] reported a meta-analysis of 13 retrospective, case-control studies on robotic and laparoscopic hepatectomy conducted between 2010 and 2017. The analysis evaluated the intraoperative and short-term outcome in 435 cases of robotic hepatectomy and 503 cases of conventional laparoscopic hepatectomy in Italy, China, France, the United States, Korea, Germany, and Belgium. The results showed that compared with conventional laparoscopic hepatectomy: (1) Intraoperative parameters indicated that robotic hepatectomy had a longer operative time (MD = 65.49 min; 95%CI: 42.00, 88.98) and increased intraoperative blood loss (MD = 69.88 mL; 95%CI: -27.11, 112.65), but there were no significant differences in blood transfusion rate [odds ratio (OR) = 0.96; 95%CI: 0.47, 1.97] and conversion rate (OR=0.75; 95%CI: 0.45, 1.25); (2) there were no statistically significant differences in the overall complication rate (OR = 0.80; 95%CI: 0.56, 1.14), major complication rate (Clavien-Dindo grade III or higher[67]) (OR = 1.0; 95%CI: 0.49, 2.06), R1 resection rate (OR = 1.03; 95%CI: 0.41, 2.55), and LOS (MD = 0.12 d; 95%CI: -0.52, 0.77); (3) the overall hospital cost of robotic hepatectomy was higher than that in the laparoscopic group (MD = 4.24, 95%CI: 3.08, 5.39); (4) sub-group analysis on robotic hepatectomy and conventional laparoscopic hepatectomy conducted after 2010 showed that the robotic group had a lower conversion rate (OR = 0.34; 95%CI: 0.13, 0.87), and there were no statistically significant differences in operative time and intraoperative blood loss.

The meta-analyses published by Qiu *et al*[72] and Montalti *et al*[73] had also drawn similar conclusions. In addition, the meta-analysis published by Hu *et al*[74] in 2018 that analyzed the efficacy of robotic surgery in liver tumors also obtained similar conclusions. The analysis also found that the robotic group had a longer postoperative fasting time (weighted MD = 1.2, 95%CI: 0.24, 2.17), but the two groups showed no significant difference postoperative mortality (OR = 0.67, 95%CI: 0.16, 2.83). Subgroup analyses in some studies had suggested that the robotic group may be superior to conventional laparoscopic surgery when used for major hepatectomy[46] or tumors localized in the superior and posterior segments[61]. In 2018, Marino *et al*[75] compared laparoscopic right hepatectomy (n = 20) and robotic right hepatectomy (n = 14) and found that the robotic group had shorter operative time than the laparoscopic group (425 ± 139 *vs* 565.18 ± 183.73 min, P = 0.022), whereas intraoperative blood loss, postoperative complications, LOS, and surgical costs were not significantly different between the groups.

Although the flexibility and the clarity and stability of the visual fields are more superior in the robotic laparoscopic surgical system than in conventional laparoscopic surgery, minimally-invasive hepatectomy is still currently predominated by conventional laparoscopy[17,18]. Studies have indicated that compared with conventional laparoscopic hepatectomy, robotic hepatectomy has a longer operative time, increased intraoperative blood loss, and a higher cost, whereas no significant differences are observed with regard to blood transfusion rate, R0 resection rate, LOS, overall complication rate, and severe complication rate between the two groups. With the accumulation of surgical experience, the conversion rate of the robotic group gradually decreases.

Recommendation 4: As minimally invasive surgery, robotic hepatectomy has similar effectiveness for liver malignancy disease compared to laparoscopic hepatectomy. Regarding the oncological outcome there is no significant difference in the radical resection rate, overall survival rate and recurrence rate between robotic hepatectomy and laparoscopic hepatectomy. Level of evidence: Very low. Level of recommendation: Weak (Grade 2D)

Khan *et al*[76] evaluated the long-term oncologic outcomes of patients undergoing robotic liver surgery (n = 61) for primary hepatobiliary malignancies between 2006 and 2016 and showed that the R0 resection rates of hepatocellular carcinoma, intrahepatic cholangiocarcinoma, and gallbladder carcinoma were 94%, 68%, and 81.8%, respectively. The median follow-up time was 75 mo (95%CI: 36,113), 5-year overall survival and disease-free survival were 56% and 38%, respectively, and the 3-year survival rates of hepatocellular carcinoma, intrahepatic cholangiocarcinoma, and gallbladder cancer were 94%, 65%, and 49%, respectively.

Hu *et al*[77] published a meta-analysis of 17 retrospective, case-control studies on robotic and laparoscopic hepatectomy conducted between 2010 and 2017. The analysis evaluated the intraoperative and short-term outcomes in 487 cases of robotic hepatectomy and 902 cases of conventional laparoscopic hepatectomy in Italy, China, France, the United States, Korea, Germany, and Belgium. The results showed that compared with conventional laparoscopic hepatectomy, there was no significant difference in R0 resection rate (OR = 2.20, 95%CI: 0.78, 6.23) and R1 resection rate (OR = 1.10, 95%CI: 0.45, 2.73) between two groups. The meta-analyses published by Qiu *et al*[72], Guan *et al*[71] and Montalti *et al*[73] had also drawn similar conclusion. As there are few comparative studies on long-term prognosis, there is no meta-analysis report on the long-term prognosis of robotic hepatectomy and laparoscopic hepatectomy. Lai *et al*[39] reported a single-center study evaluating the long-term prognosis of patients with liver cancer treated with robotic hepatectomy (n = 100) and conventional laparoscopic hepatectomy (n = 35) and found that compared with conventional laparoscopic surgery, the robotic hepatectomy for liver cancer had no statistically significant differences in R0 resection rate (96% *vs* 91.4%, P = 0.72), 5-year overall survival (65% *vs* 48%, P = 0.28), and 5-year disease-free survival (42% *vs* 38%, P = 0.65). The report from Troisi[49] evaluated the long-term prognosis of patients with colorectal cancer liver metastases who underwent robotic hepatectomy (n = 24) and conventional laparoscopic hepatectomy (n = 108), and the results showed that the 1-year and 3-year disease-free survival rates were 79% and 62% in the robotic group and 81% and 41% in the open hepatectomy group.

Recommendation 5: For minor hepatectomy, robotic hepatectomy as safe and feasible as laparoscopic hepatectomy and open hepatectomy. Robotic hepatectomy has longer operative time than laparoscopic hepatectomy for minor hepatectomy. The intraoperative blood loss, overall postoperative complication rate and overall cost of robotic minor hepatectomy are comparable to that of laparoscopic minor hepatectomy. Level of evidence: Very low. Level of recommendation: Weak (Grade 2D)

Based on the published articles, the minimally-invasive hepatectomy is mainly used in minor hepatectomy, which includes resections of the left lateral lobes and local liver lesions. Tsilimigras *et al*[27] systematically reviewed 31 comparative studies between 2008 and 2017 that included a total of 1148 patients and found that robotic minor hepatectomy accounted for 72.7% of all robotic hepatectomy cases, with a mean operative time of 242.2 ± 89 min, intraoperative blood loss of 317.1 ± 331 mL, conversion rate of 8.1%, mean postoperative hospital stay of 6.1 ± 2.9 d, and incidence of postoperative complications of 14.8%. The meta-analysis published by Guan *et al*[71] included 5 retrospective, case-control studies on robotic and laparoscopic liver surgeries conducted between 2010 and 2017, including 95 cases of robotic minor hepatectomy and 163 cases of conventional laparoscopic minor hepatectomy. The evaluation of intraoperative and short-term postoperative outcomes showed that compared with conventional laparoscopic minor hepatectomy, robotic minor hepatectomy had a longer operative time (MD = 50.29 min; 95%CI: 10.52, 90.05), but there were no significant differences in perioperative outcomes such as intraoperative blood loss and complications. Laparoscopic hepatectomy is currently recommended for left lateral segmentectomy[78]. Salloum *et al*[79] published a single-center study comparing robotic left lateral segmentectomy (*n* = 16) and laparoscopic left lateral segmentectomy (*n* = 80) and showed that the 2 groups had no statistically significant differences in operative time (190 *vs* 162 min, *P* = 0.10), intraoperative blood loss (247±239 *vs* 206 ± 205 mL, *P* =0.50), overall complication rate (12% *vs* 11%, *P* = 0.77), LOS (7 ± 8 *vs* 6 ± 4 d, *P* = 0.74), and total cost (5522€ *vs* 6035€, *P* = 0.70).

Recommendation 6: For major hepatectomy, robotic hepatectomy as safe and feasible as laparoscopic hepatectomy and open hepatectomy. Robotic hepatectomy has longer operative time than laparoscopic hepatectomy for major hepatectomy. The intraoperative blood loss, overall postoperative complication rate and overall cost of robotic major hepatectomy are comparable to that of laparoscopic major hepatectomy. There is no significant difference in the operative time, intraoperative blood loss and complication rate between robotic hepatectomy and open hepatectomy for minor hepatectomy. Level of evidence: Very low. Level of recommendation: Weak (Grade 2D)

Nguyen *et al*[64] reviewed the current status of laparoscopic hepatectomy in 127 studies worldwide. Based on the definition of major hepatectomy stated in the Fukuoka Declaration[78], they found that major hepatectomy accounted for 17.3% of all laparoscopic hepatectomy cases. In view of the disadvantages of conventional laparoscopy such as limited flexibility, fulcrum effect, and poor visual field stability, it is believed that robotic hepatectomy may compensate the limitations of conventional laparoscopic surgery in major hepatectomy, such as hemi-hepatectomy and extended hepatectomy, which require precise dissection of the porta hepatis[80]. Tsilimigras *et al*[27] systematically reviewed 31 comparative studies between 2008 and 2017 and found that robotic major hepatectomy (*n* = 115) accounted for 27.3% of all robotic hepatectomy cases, with a mean operative time of 403.4 ± 107.5 min, intraoperative blood loss of 543.4 ± 371 mL, conversion rate of 8.6%, mean LOS of 10.5 ± 4.8 d, and complication rate of 17%.

Giulianotti *et al*[81] reviewed 24 cases of right hepatectomy conducted by a single surgical team between 2005 and 2010. The results showed that the mean operative time was 337 min, mean intraoperative blood loss was 457 mL, blood transfusion rate was 12.5%, conversion rate was approximately 4.2%, and incidence rate of postoperative complications was 25%. No perioperative mortality occurred, and the perioperative outcome was similar to that of laparoscopic hepatectomy conducted during the same period. Spampinato *et al*[48] compared robotic hemi-hepatectomy (*n* = 25) and laparoscopic hemi-hepatectomy (*n* = 25) in their study, which conducted in 2 centers in Italy and Belgium between 2009 and 2012. The results showed that the 2 groups had no statistically significant differences in operative time (430 *vs* 360 min, *P* = 0.070), intraoperative blood loss (250 *vs* 400 mL, *P* = 0.95), conversion rate (4% *vs* 4%, *P* =1), overall complication rate (16% *vs* 36%, *P* = 0.2), R0 resection rate in malignant tumors (100% *vs* 91%, *P* = 0.49), and LOS (8 *vs* 7 d, *P* = 0.48). According to the definitions of minimally-invasive major hepatectomy in the Fukuoka Declaration[78] and Louisville Declaration[4], when considering the difficulty of the surgery, resections of lesions in the superior posterior segments of the liver should also be classified as major hepatectomy. Patriti *et al*[44] compared the efficacy of robotic hepatectomy (*n* = 19) and open hepatectomy for the resection of liver segments 6 and 7 in 2 centers in Italy. Compared with open hepatectomy, robotic hepatectomy had a longer operative time (303 ± 132.3 *vs* 233.9 ± 81 min, *P* = 0.002). There were no statistically significant differences with regard to the volume of intraoperative blood loss (376.3 ± 410 *vs* 457.5 ± 365.5 mL, *P* = 0.40), overall complication rate (15.8% *vs* 13%, *P* = 0.70), severe complications rate (5.3% *vs* 1.4%, *P* = 0.80), and LOS (6.7 ± 3 *vs* 7.9 ± 4.4 d, *P* = 0.60).

Recommendation 7: Robotic liver donor hepatectomy could be an alternative. The procedure should only be performed by experienced surgeons, and the true benefits of robotic donor hepatectomy need further investigation in the future. Level of evidence: Very low. Level of recommendation: Weak (Grade 2D)

In 2012, Giulianotti *et al*[16] reported for the first robotic living-donor hepatectomy of the right inferior lobe. Compared with conventional laparoscopic surgery, the robotic surgical system provided a magnified and stable 3D field of vision with higher accuracy in intraoperative suture during the living-donor hepatectomy[82]. At present, countries such as Italy, South Korea, China, and India have carried out robotic living-donor hepatectomy, but no report has been published on robotic liver transplantation[6,16,83-86].

The only comparative study on robotic living-donor hepatectomy and standard open living-donor hepatectomy was published by Chen *et al*[83], which was a retrospective, case-control study on 13 cases of robotic hepatectomy and 54 cases of open hepatectomy conducted at a single center between May 2013 and August 2015. The results showed that the robotic group had a longer operative time (596 *vs* 383 min, $P < 0.001$), reduced dosage of postoperative analgesics (0.58 *vs* 0.84 ng/kg, $P = 0.03$), and a higher postoperative cost (13436$ *vs* 5019.1$, $P < 0.001$), but there were no significant differences in intraoperative blood loss, LOS, and overall complications. No open conversion was required in the robotic group. Even though robotic living-donor hepatectomy is considered safe and feasible based on published case and case series reports and comparative studies, it does not show significant superiority in therapeutic efficacy compared with open and conventional laparoscopic approaches. Although robotic living-donor hepatectomy is technically safe and feasible, critics have pointed out that minimally-invasive surgery for living-donor hepatectomy cannot be truly considered as "minimally-invasive surgery", as it merely moves the midline incision to the lower abdomen at the cost of increasing 3 to 5 small incisions for port sites. Therefore, it should be considered as "minimal incision surgery"[59]. Furthermore, the complex anatomy of the liver, together with the absence of inflow control and the need for a short ischemic time, may result in a higher risk for both donor and graft safety[60].

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